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Evaluation of a Multi-Functional Machine for use in Sanitary Landfill Operations in Sparsely Populated Areas

Battelle Memorial Institute

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EVALUATION OF A MULTI-FUNCTIONAL MACHINE FOR USE IN SANITARY LANDFILL OPERATIONS IN SPARSELY POPULATED AREAS

Final Report on a Solid Waste Management Demonstration Grant

This report (SW-39d) on work performed under
solid waste management demonstration grant no. G06-EC-00210
to the Pacific Northwest Laboratories,
of Battelle Memorial Institute, was written by
V. L. HAMMOND

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1972

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The report gives details of an investigation made of a multi-functional machine, known as the Multi-Mover, which was originally designed to perform the functions of a crawler tractor/dozer, dump truck, compactor, and loader. Its performance in accomplishing sanitary landfill and earthmoving operations was evaluated at several sites in Idaho and Oregon to determine its effectiveness both absolutely and in comparison with crawler tractors in compacting waste and soil cover material, excavating and spreading soil cover, and distributing refuse for compaction. Since the machine is a rubber-tired vehicle that can move over highways under its own power, its use at scattered sites in a sparsely populated area was also evaluated. The advantages and disadvantages that result from the basic concept of a multi-functional machine are presented, the economics of purchase and operation are analyzed, and certain modifications are recommended.

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EVALUATION OF A MULTI-FUNCTIONAL MACHINE FOR USE IN SANITARY LANDFILL OPERATIONS IN SPARSELY POPULATED AREAS

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Battelle Memorial Institute

INTRODUCTION AND BACKGROUND

A multi-functional machine, known as the Multi-Mover, was invented and patented by Ike J. Wardle, Boise, Idaho. The machine is a rubber tired vehicle that performs the function of a crawler tractor dozer, dump truck, compactor, and loader. Mr. Wardle was working as a heavy-equipment operator for a construction firm in the early '40s when he began thinking of improvements for the machinery he was using. He concluded if the apron used for pushing on ordinary earthmoving machines such as crawler tractors could be hinged and mounted on a hydraulic arm, it could pull material into or out of an integral box equivalent to a dump truck box. Mr. Wardle reasoned that a single piece of equipment so configured should be more efficient than separate units, such as bulldozer and dump truck, working together.

His concept of the hinged apron was still in the formative stage when he was captured by the Japanese while working with a civilian construction crew on Wake Island during World War II. During his internment he perfected the concept, determining the most effective hinge point and radius arm configuration. In 1956 Mr. Wardle was awarded two basic patents on the design. One was for the hinged-arm claw-apron. The other was for the drive-chain configuration and the machine's frame, which forms a "Y" configuration, with the box in the fork of the "Y". The engine is located at the driver's end of the machine on the stem of the "Y".

The results of this first venture were mixed. Although the design proved to be basically sound, the machine lacked hydraulic power and had other deficiencies. Wardle redesigned parts of the machine and completed the second Multi-Mover by 1959. After extensive testing, the second design was ready for production but for various reasons additional machines were never produced. The second machine was used for five years in a sand and gravel operation. Subsequently, Enterprises Inc., an Idaho-based firm, acquired the rights to the design. Its subsidiary, Nampa Sanitary Service, operated a sanitary landfill for disposal of solid wastes from Nampa and Canyon County, Idaho. Enterprises Inc. recognized the potential of the machine for use on landfills, but was hampered by lack of funds.

The Multi-Mover is a machine originally designed to perform the functions of a crawler tractor/dozer, dump truck, compactor, and loader. Use of the Multi-Mover in these capacities as a earthmover created interest in using it to perform the operations for proper sanitary landfill management. A properly equipped crawler tractor is the usual machine used on a sanitary landfill, but it was believed the Multi-Mover could perform more efficiently and economically, particularly in maintaining a number of widely scattered landfills in a sparsely populated region.

Proper operation of sanitary landfills, where they are scattered across a sparsely populated area, is a difficult problem mainly because of the costs and inconvenience involved in site-to-site equipment transfer. As a result, open dumps are the usual situation. The Multi-Mover is a rubber tired vehicle that can be moved on the highway under its own power, (as opposed to the crawler tractor, which requires a prime mover for transportation) and offers the possibility of being more economical to use on scattered sites in a sparsely populated region.

In 1969 Battelle-Northwest in cooperation with Enterprises, Inc., received a demonstration grant from the Bureau of Solid Waste Management of HEW* to evaluate the machine. A three-phase demonstration program was carried out to evaluate the

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* Now the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency (EPA).

Multi-Mover in sanitary landfill operations and study the solid waste disposal problem in Canyon County, Idaho. The first phase consisted of modification and renovation of the ten-year-old Multi-Mover; the second phase provided for field evaluation and data collection and the third phase consisted of five parts as follows:

a. Systems analysis of solid waste disposal in a sparsely populated area.

b. An economic and industrial growth study of Canyon County, Idaho, to define present and expected future solid waste generation.

c. A market survey to determine the demand for multi-functional machines in sanitary landfill operations throughout the country.

d. An operations and cost effectiveness analysis to determine the best way to use multi-functional equipment of this type.

e. Transportation problems connected with moving equipment from one site to another.

SUMMARY AND CONCLUSIONS

An engineering review of the Multi-Mover was performed to assess the repair work required to make the subject machine operable, and determine the modifications required to make it reasonably suited to perform subsequent landfill work. Every major assembly was inspected, and excessively worn parts were either replaced or rebuilt. Major modifications were made to all hydraulic systems and a dual hydraulic brake system was installed. Also, many minor modifications were made to the engine and other major mechanical assemblies.

Performance of the Multi-Mover in accomplishing sanitary landfill and earthmoving operations was evaluated at several sites in the states of Idaho and Oregon. The purpose of the field tests was to determine the effectiveness of the Multi-Mover both absolutely and in comparison with crawler tractors in compacting waste and soil cover material, excavating and spreading soil cover, distributing refuse for compaction, and transportation from site-to-site. A special trip was made to evaluate long distance highway travel and operations under winter conditions.

The basic concept of the Multi-Mover -- that of a multi-functional machine -- results in a unit which has certain disadvantages when compared to a single purpose machine, such as a dozer, carryall, and blade. These disadvantages include such things as limited carrying capacity, longer turning radius, low ground clearance, and inadequate power or speed for some operations. However, these disadvantages are less significant when considering applications such as a small sanitary landfill, where the multiple capabilities of the Multi-Mover would permit it to replace several single purpose machines. Some of the disadvantages could feasibly be reduced in impact or eliminated in subsequent models. These include too large a turning radius and inadequate power and minimum speed. Other disadvantages, such as the limited carrying capacity, are inherent in a design that yields a machine small enough for general highway travel. Even so, the machine still carries more load than front loaders of similar size.

From the results of the field tests, we conclude the Multi-Mover (27,225 lb) to be approximately equivalent in compaction effectiveness to a heavier crawler tractor (33,757 lb) and markedly superior to a lighter crawler tractor (21,000 lb).* In spite of mechanical deficiencies of the machine in its present design, it is capable of performing satisfactorily, at a lower cost, all of the functions of a crawler tractor in sanitary landfill operations. In addition, it can function as a snow removal vehicle and it can be driven from site-to-site economically at distances up to 12 or 15 miles to service landfills in sparsely populated counties.

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* EPA Comment: Based partially on visual observations.

The results indicate that the Multi-Mover in its present configuration would be an economical general purpose landfill machine for operation in sparsely populated counties, and that certain modifications would improve its compaction capabilities and overall reliability. The machine is judged worthy of additional demonstration after its ground clearance is increased and miscellaneous mechanical features are improved.

The cost-effectiveness of the Multi-Mover was also compared to that of the crawler tractor. Questionnaires were mailed to sparsely populated counties and to towns and cities in sparsely populated areas to determine the type of equipment currently in use. Data obtained from time and motion studies were used to develop time/unit work effectiveness parameters for each machine in performance of the tasks required for landfill operations. Cost estimates, which included both the capital and operating costs, were developed on a per operating hour basis. The cost and effectiveness parameters were combined to obtain a cost/ unit work measure of cost-effectiveness. Both the cost and effectiveness estimates were analyzed to determine the sensitivity of the final estimate to estimates of the various input data.

A computer model was developed to study the economics of operating several remote solid waste disposal sites. The model optimizes the assignment of equipment to service each site, including both transportation of equipment and performance of the tasks required in sanitary landfill operation. The model user must provide parameters describing both capabilities and operating costs of the equipment and parameters describing the operation of his disposal sites.

The model was used in this study to compare the effectiveness of the Multi-Mover with the effectiveness of a bucket-equipped crawler tractor. The parameters for this study were obtained from other sections of the program. With the parameters provided, the Multi-Mover demonstrated a definite cost advantage over the crawler tractor.

Potential interest in the Multi-Mover was determined by a mail survey of 15% of the sparsely populated counties in the United States. Forty percent of the counties which operated sanitary landfills expressed an interest in the machine. A similar survey was made of selected towns and cities in sparsely populated areas in the Pacific Northwest and Northern California, and 44% indicated interest in the Multi-Mover. Comments solicited on the practicability of the Multi-Mover showed a tendency to question the reliability of such a complex machine, the suitability of rubber tires for landfill services, and the expected high purchase price of the machine. Projection of market potential based on these surveys show an initial market for 1000 machines over the next several years.

The problems of solid waste generation, collection, transportation and disposal in sparsely populated areas were examined with particular emphasis on ways in which a multi-functional earthmoving machine such as the Multi-Mover could contribute to their solution. Canyon County, Idaho, was used as an example of a sparsely populated area.

Sparsely populated areas are not likely to provide collection service for all their residents, and the disposal of wastes by residents can cause health hazards through land and water pollution. The low population density makes all solid waste services more expensive on a per person basis. Consolidation of services through transfer operations and multi-site servicing on a rotating basis appear to be feasible ways of reducing the cost per person. Also, consolidation of solid waste planning and management on a regional basis would encourage consolidation of services of adjacent areas and would allow the cost of improved management and planning to be shared among a larger number of people.

A mail survey was made to determine what the county officials in sparsely populated areas consider their most serious problems, and the Multi-Mover's possible contributions to solution of these stated problems were analyzed. The Multi-Mover's superior cost effectiveness would contribute to the solution of many of these problems by lowering the overall costs of the disposal operations. Its high capital cost is the most serious drawback. Even though its overall cost per unit work would be lower than that of a crawler tractor, the financial structure of governments in sparsely populated areas tends to favor lower expenditures for capital equipment over lower operating costs in a trade-off.

Canyon County's resource base was examined to identify those key land, water, mineral, agricultural, industrial, and human resources upon which the county economy depends. These resources were evaluated with consideration for the region's competitive position in the Pacific Northwest and national markets. Projections were made of Canyon County's economic profile to 1990 with emphasis placed on translating projected changes in the mix of local manufacturers and their growth to effects on solid waste generation. The same was done for commercial and residential solid waste generation to 1990. These solid waste projections were made with recognition that technology is being developed in response to pollution problems associated with waste materials and in response to pressures to find innovative economic uses for these materials.

The volume of industrial solid waste is projected to increase by 32% during the 1970 to 1990 period. This includes the wastes from manufacturing firms engaged in processing agricultural products. Nearly all the county's manufacturing firms are located in or near the Nampa-Caldwell area. Commercial waste generated from retail, wholesale and other service industries is expected to increase 58% during the same period. Nearly 90% of this material is generated in the Nampa-Caldwell area. Residential solid waste, which makes up a majority of the county's solid waste, is projected to increase 40%

on a county-wide basis. Within the Nampa-Caldwell area, residential solid waste is projected to increase 61%, while residential solid waste generation in the rest of the county is projected to increase 19%.

Projected increases in county-wide solid waste generation to 1990 are affected only to a small degree by manufacturing industries (14%), moderately by commercial industries (27%) and to a high degree by residential solid waste (59%). Total solid waste input to the county's disposal site is projected to increase by 24% by 1980, while the 1990 level is projected to be 60% above the 1970 level.

RECOMMENDATIONS

Multi-functional Machine Recommendations

The basic concept of the Multi-Mover is sound. A versatile machine with highway mobility is needed to service landfills in sparsely populated areas, and a well engineered, reliable Multi-Mover would fill this need. It is therefore recommended that the Bureau of Solid Waste management sponsor an incentive program to aid in developing a marketable Multi-Mover. The incentive program should aid in developing the machine to a point where it is competitive on the basis of operability and reliability with the usual sanitary landfill equipment produced by major heavy equipment manufacturers.

As the future development of the Multi-Mover is not a responsibility under this grant, engineering recommendations based on the evaluations described in this report are offered to guide those who may undertake future engineering of the Multi-Mover. In this pursuit the following are recommended:

- Increase Machine Power

  An engine of greater horsepower (225-250 hp) well matched to the transmission and drive train would greatly improve Multi-Mover performance. A lower minimum speed (less than 3 MPH) without sacrifice of top speed (at least 30 MPH) would improve the machine's earthmoving performance.

- **Increase Machine Maneuverability**

  The machine's efficiency could be greatly improved if the turning radius were shortened. This would require a different design than that presently used. Consideration should be given to articulating the machine to increase its maneuverability.

- **Simplify and Improve Control of Machine**

  The rotatable drive station turret should be replaced with two fixed operator seats and with controls easily accessible from either operator position. This arrangement could simplify control connections and eliminate the turret and turret drive mechanism. Positioning the operator where he could see the depth of the cut would improve the grading ability of the machine. Loading material into the box while the machine is moving is difficult because four hand controls must be operated. These are the steering wheel, depth of blade control, and the claw control and claw arm control. The claw and claw arm control should be operated with a single control lever, and the claw and claw arm mechanisms should be automatically programmed for loading cover on a selectable basis. With automatic operation of the claw and claw arm the operator would only need to control the depth of cut and steer the machine when loading cover.

An all-weather cab to enclose the operator is desirable as optional equipment.

- Increase Machine Ground Clearance

  The Multi-Mover ground clearance is 10 in. and should be increased to at least 18 in. With the present clearance the box drags when the machine is being used for waste compaction. On occasion the bottom of the box would drag on waste that had been compacted and tear out large pieces.

- Improve Machine Loading

  When the blading end of the box is lowered on a loading run, it creates a fairly steep angle, and the earth being loaded must be pushed up this inclined plane. This allows only partial loading of the box and with wheel power only. If the back of the box could be lowered along with the front to decrease this angle, loading efficiency would improve greatly. The location of the pivot point, length of claw arms and rotation of the claw need to be optimized in relation to the box to obtain the most efficient design. The most efficient method for design optimization would employ kinematic analysis and provide for modeling.

- **Redesign Machine Claw and Claw Arm**

  Power to operate the claw and claw arm should be increased as much as possible and consideration should be given to a "back-hoe" design claw and claw arm to facilitate the loading of cover from a stockpile or bank.

- **Fit Machine with Larger Tires and Chains**

  Steel belted tires should be tried on machines built in the future. These tires were not available in the required size during the evaluation, but probably could be obtained in the future if a minimum demand is demonstrated or guaranteed.

  Clearance between the tires and other parts of the machine should be provided to allow the use of tire chains when operating in mud, snow, or on ice.

Recommendations to Improve Solid Waste Management in Sparsely Populated Areas

1. One of the most serious problems of solid waste management in sparsely populated areas is the lack of adequate planning. Solid waste operations are carried out on a day-to-day basis and there is little effort to develop plans past the current fiscal year. The lack of planning generally arises from a lack of knowledgeability of solid waste management on the part of local governmental management. Frequently the responsibility falls to the county commissioners, who characteristicly have little time to devote to the project and little expertise in the field. From standpoints of cost and specialized knowledge, sparsely populated counties and the small cities and towns in sparsely populated areas cannot individually support the planning necessary for their area. Regional planning for solid waste could help solve this problem both by spreading the cost of a good planning program over the tax base of a larger area, and amalgamating experience and expertise of individual city and county governments to support the planning.

Daily management of solid waste in sparsely populated areas suffers from the same problems as planning. Responsibility for waste operations often falls to an organization such as the county engineer's office (road department). Solid waste operations are often a small part of the agency's responsibilities and do not get the attention they require. It is also unlikely that the manager has adequate training in solid waste operations. These problems could be approached on a regional basis with the same benefits that are expected from a regional planning function. In addition, regional management would encourage and facilitate consolidation of solid waste operations, which would alleviate present duplication of effort and provide some economics of scale. This approach would also help to free solid waste programs from local politics. A well planned demonstration should be supported to compare the regional solid waste program with the existing situation both in terms of economic cost and the usual level and quality of solid waste services provided.

2. Another serious problem in sparsely populated areas is the apathy of the citizenry toward the problems of solid waste. Most citizens in this type of area are not aware of the problems of solid waste disposal and the apathy is of course reflected in the attitudes

of elected representatives who have the responsibility for the solid waste program. One surveyed County Commissioner's analysis of solid waste problems was, "It doesn't take any brains to dig a hole and bury garbage in it." More emphasis on public information programs to inform the citizens of the problems and to elicit support for their solution is recommended. This appears for two reasons to be a prerequisite to any significant improvement. First, the public's cooperation is essential to a successful operation (particularly in a sparsely populated area where many of the people must dispose of their own solid wastes). Second, the elected officials must see that their constituents desire improvements and are willing to pay the necessary costs.

3. Additional research into transfer operations in sparsely populated areas appears justified and is recommended. It may be less expensive to move the waste of an area to one disposal site rather than maintain several disposal sites. The choice among transfer operations, independently maintained sites and jointly maintained sites (several sites maintained by one crew on a rotating basis), is one which depends on the exigencies in each individual case. However, in general it appears that transfer operations should allow some savings to be realized and should be the most easily adaptable to future changes in disposal methods (e.g., increased separation for salvage and recycling).

DISCUSSION

Phase I -- Machine Modification and Renovation

The Multi-Mover was about 10 years old at the start of this project, and required extensive renovation to restore it to a level acceptable for objective evaluation of its capabilities. The modification and renovation process began with a formal engineering review of the machine and its suitability for landfill service. It culminated in incorporation of the resulting recommended design changes and performance of extensive corrective maintenance. The following description describes the modified machine.

Multi-Mover Description. The Multi-Mover (Figure 1) is a multi-functional machine which performs the functions of four pieces of earthmoving equipment (crawler tractor dozer, dump truck, compactor, and loader). It was developed originally for filling, grading and compacting on construction jobs; has selectable four-wheel drive capability; and can travel at speeds sufficient for highway travel. Table 1 lists pertinent Multi-Mover specifications.

A three point suspension system is used on the machine. This assures that all four wheels will maintain contact even when traveling over rough terrain. The wheels on the side frame alongside the box are in a fixed position relative to the frame. The wheels on the steering end of the machine

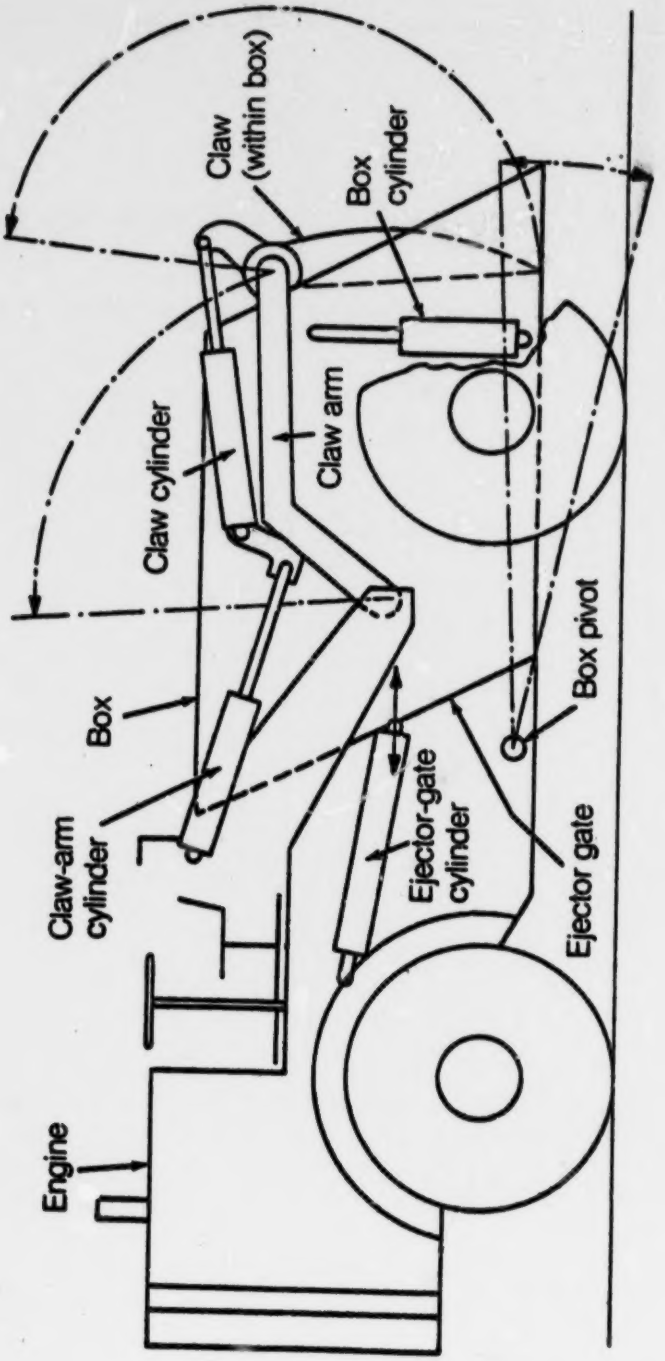
Engine
Claw-arm cylinder
Box
Claw cylinder
Claw (within box)
Ejector-gate cylinder
Claw arm
Box cylinder
Ejector gate
Box pivot

TABLE 1

MULTI-MOVER SPECIFICATIONS

POWER TRAIN

ENGINE

Make	Waukesha
Model	135-DKBS-Turbocharged
Horsepower	167 (max.)
RPM	2400
Torque, lb-ft	400
Fuel Tank Capacity, (gal.)	50

TRANSMISSION

Make	Allison	
Model	CRT-3331-1 (torque converter)	
Ranges	FORWARD	REVERSE
Low	5.27:1	5.11:1
Intermediate	1.91:1	1.85:1
High	0.659:1	0.639:1

AXLES AND HUBS (4WD)

Front Steering Axle and Hub	Timken Detroit PS-150HX-2	(16.65:1)
Jack Shaft Axle	Timken Detroit QT-140-B-2	(4.625:1)
Rear Hubs	Timken Detroit PR-20	(3.6:1)

HYDRAULIC SYSTEM

BLADE, EJECTOR GATE, CLAW AND CLAW-ARM CYLINDERS: Eight (two each) commercial shearing and stamping cylinders.

PUMPS: Zeno dual pump, 32 and 56 gal/min @1000 lb/in.^{2} and 1800 rpm; Vickers variable displacement pump, 45 gal/min @ 1000 lb/in.^{2} and 1800 rpm.

VALVES: Four Hoen pilot-operated hydraulic control valves.

RESERVOIR: 70 gal.

PILOT CONTROL SYSTEM: Eight "Hydronic" master-slave hydraulic units to operate the hydraulic valves, engine throttle and transmission controls.

TABLE 1 (Continued)

RUNNING GEAR

STEERING	
Type	Power-assisted manual operation
Turning Radius	
Left	39.5'
Right	56.5'
TIRES	1600 x 20
BRAKES	Dual vacuum-assisted hydraulic systems with four-wheel hydravac-over-hydraulic 17" x 4" drums

WEIGHT AND DIMENSIONS

WEIGHT, LB	27,225 (unladen)
DIMENSIONS	
Length	22'
Width	8' 6"
Height	8'
Ground Clearance	10" (Box Raised)

OPERATING DATA

TRAVEL SPEEDS

	Forward (MPH)		Reverse (MPH)
Engine RPM	Max	Min	Min
2000	30	3.4	3.5
2400	35	-	-

HYDRAULIC CYCLE SPEEDS	
Claw Arm	6.8 sec up and 2.0 sec down
Claw	5.0 sec out and 6.0 sec in
Box (empty)	2.8 sec up and 1.0 sec down
Gate (w/empty box)	
Box raised	11.0 sec out and 17.0 sec in
Box down	9.5 sec out and 24.0 sec in
BOX CAPACITY	5.5 yd^3 (Level -- Box raised)

are mounted on an assembly which is free to swivel about the longitudinal axis of the machine, permitting these wheels to tilt as needed to maintain ground contact.

The machine has a hinged box that is lowered for scraping, then raised for transporting material. A claw, supported on movable arms on each side of the box, can be used to scoop material piled ahead of the machine into the box as the machine advances.

The wheels on either side of the box are permanently engaged to the engine through a drive system consisting of an Allison transmission, a differential, and chain and sprocket drives which are located in the side frames that support the box. The front wheels are steerable and are driven from the transmission through a manually controlled clutch to a differential on the axle shafts.

The operator's turret is reversible to permit the driver to face forward regardless of the direction of machine travel. It is rotated electrically using a turret-mounted control.

The machine is hydraulically controlled except for steering, which is manually operated through a power-assisted system. A pilot control system using "Hydronic" master-slave units is used to position the main hydraulic control valves for the box, ejector gate, claw, and claw arm hydraulic circuits, as well as the transmission controls and engine throttle.

The primary hydraulic system (Figure 2) consists of a Zeno dual pump, mounted on the transmission, a Vickers variable displacement pump driven from the engine power takeoff, four Hoen pilot operated hydraulic control valves, and eight Commercial Shearing and Stamping hydraulic cylinders used to operate the ejector gate, claw, claw arm, and box. The hydraulic fluid is continuously filtered in the reservoir tank. These filters, which are equipped with plugging indicators and incorporate magnets for trapping ferrous materials have a built-in bypass that functions only if the filter clogs.

The Multi-Mover has a dual braking system. Separate reservoirs, hydraulic lines, and vacuum boosters are provided for the front and rear brakes.

Engineering Review. The engineering review was performed before renovation began. This consisted of a visual inspection of the machine; discussions with the inventor; and analysis of the drive train, hydraulic power systems, and brake system.

The visual inspection showed that the box, claw and claw arm were badly worn. Numerous hydraulic system leaks were noted, as well as the use of uncoded pressure fittings. While the motor would run, hydraulic pressure was inadequate indicating that the pumps would require service. Major components were missing from the pilot control system and the operator's turret was inoperable. The tires were badly worn. The main frame was cracked near the motor mounts.

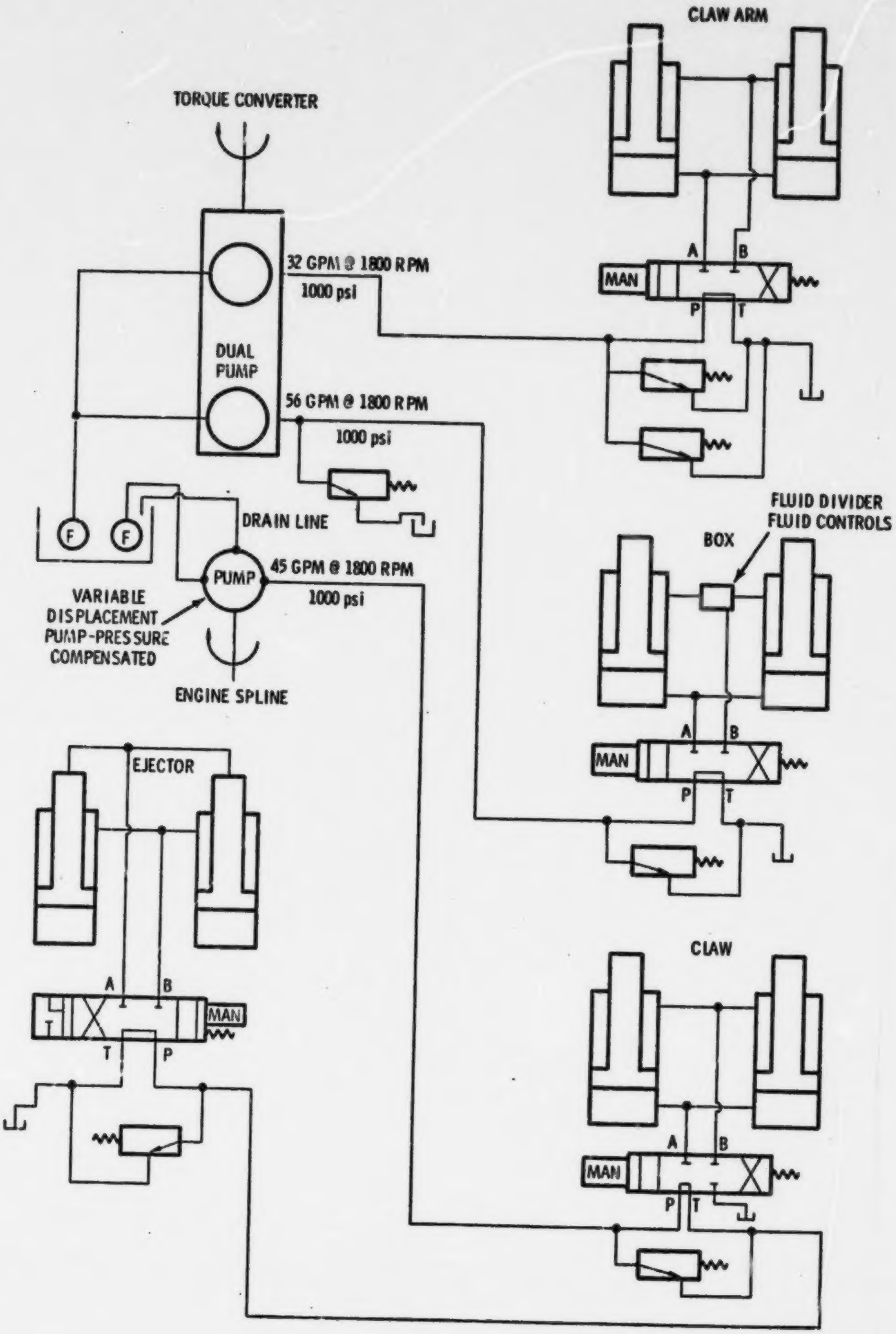
CLAW ARM
TORQUE CONVERTER
32 GPM @ 1800 RPM
1000 psi
DUAL PUMP
56 GPM @ 1800 RPM
1000 psi
A
B
MAN
P
T
F
F
DRAIN LINE
PUMP
45 GPM @ 1800 RPM
1000 psi
VARIABLE DISPLACEMENT PUMP-PRESSURE COMPENSATED
ENGINE SPLINE
FLUID DIVIDER FLUID CONTROLS
BOX
A
B
MAN
P
T
EJECTOR
A
B
MAN
T
P
CLAW
A
B
MAN
P
T

Figure 2. Revised Hydraulic System

Based on the visual inspection the decision was made to replace the box, claw, claw arm, tires, and all hydraulic tubing and electrical wiring. In addition, all other components, with the exception of the motor, transmission and differentials, would be removed for inspection and replaced or repaired as needed. Repairs would be made to the main frame with these components removed.

Since the motor and transmission appeared to be operable, the recommendations of the manufacturer's representative were sought to determine what course of maintenance to follow with these components. The transmission pressure was checked with the machine operating and found to be within acceptable limits; this constituted the manufacturer's suggested serviceability test. Since the unit functioned normally, transmission maintenance consisted only of draining the old fluid, flushing the unit, and replenishing it with new fluid. Tests on the engine showed that it was generally in good condition requiring only a major tuneup and overhaul of the turbocharger.

During discussions with the inventor his drawings were found to contain a design change for relocation of the claw arm pivot points, which had not been incorporated in the subject machine. This change would modify the action of the claw, and though it had not been proven in service, it appeared to be desirable. Since the original design had already been field tested, the decision was made to try the modified design to permit a comparison of the two.

The drive train was analyzed to determine the expected maximum and minimum speeds of the machine and verify that the transmission was sized for the power output of the engine.

The drive train consists of a Waukesha 135 DKU supercharged diesel engine; an Allison transmission; and Timken Detroit front steering axle and hubs, rear jack shaft axle, and rear hubs. (The gear ratios for these units are shown in Table 1.) The expected maximum and minimum speeds for the vehicle were determined using engine speeds of 2000 and 2400 rpm. The specifications for the Allison transmission torque gave a multiplication ratio of 3.5:1 at "stall". This gave a stall speed, or speed at which transmission slippage would occur, of 1/3.5 x the minimum normal speed, or approximately 1 mph. The minimum speed for continuous operation, based on a converter efficiency of 70%, is 2.4 mph. Continuous operation slower than this could be expected to overheat the converter, according to information obtained from the transmission manufacturer.

The transmission and diesel were found to be well matched. The diesel has a maximum torque output of 350 lb-ft at 2400 rpm; however, a significant proportion of this torque is required to operate the auxiliaries -- primarily the hydraulic pumps. Therefore, the net torque input to the transmission does not exceed the transmission torque rating of 300 lb-ft. This conclusion was verified by the transmission manufacturers, who had made a similar investigation at the time the transmission was sold.

The expected cycle times were calculated at approximately 10 sec each for the claw arm, claw, and box. These times would increase when the engine slowed. The inventor felt that the desired rate for the claw and claw arm should be about one half of the calculated rate. Although the reduced times could be obtained by using larger pumps, the hydraulic system was already using up to 87 horsepower, a large percentage of engine output, and a larger engine would be required for installation of larger pumps. This would have resulted in a schedule delay as well as unduly increasing the cost of renovation. Since the original engine was in usable condition and would permit evaluation of machine capabilities, engine replacement was decided against.

The braking system was reviewed and found to be generally adequate except that it used a single hydraulic system. For safety the hydraulic booster units and the hydraulic lines would be replaced to provide a dual hydraulic brake system. The brake shoes, drums, and cylinders were adequate and could be used after inspection and overhaul.

Modifications and Restoration. Restoration was completed as required to put the machine in a condition sufficient to permit an adequate comparison with competitive landfill machinery. The basic design of the machine was not changed.

The restoration effort in this task comprised both preventive and corrective maintenance as follows:

1. *Major tuneup of engine and accessories*--This included setting the injectors, overhauling the turbocharger, overhauling or replacing engine and transmission gages as needed, adding a motor safety circuit (high temperature and low oil pressure cutouts), disconnecting the "glow" plugs (used originally for starting, but considered dangerous if used in conjunction with the current practice of injecting ether for startup), rewiring the engine, setting the governor, overhauling the starter motor and generator, rebuilding the radiator, and replacing all hoses, fan belts and filters.
2. *Inspection and repair of drive-train components*--The four planetary hubs for the wheels were disassembled, the bearings and gears were inspected and the units were reassembled with new seals. A worn inboard bearing on the left rear wheel was replaced. The universal joints between the engine and transmission were worn and were rebuilt. The drive lines from the transmission to the front and rear axles were removed, cleaned, inspected and reinstalled.

The transmission was pressure tested and found to be in satisfactory operating condition. The transmission fluid was replaced. The oil from both differentials was drained into clean containers and inspected for metallic particles. The oil was replaced along with a leaking housing seal on the front differential.

3. *Overhaul and modification of braking system*--The vacuum-assisted single hydraulic brake system was replaced with a dual system with separate reservoirs, hydraulic lines and vacuum boosters for the front and rear brakes. In addition, a low pressure safety switch with indicator on the control turrent was installed to monitor both systems.

The brake shoes were relined, the brake cylinders were rebuilt and all brake hoses were replaced. The brake drums were inspected and found in satisfactory condition.

The Bendix Vacuum pump had a broken housing. A new unit was obtained and installed. The vacuum tank used with the pump was cleaned, inspected and reinstalled. A defective check valve on the pump suction line was replaced.

4. *Replacement of tires*--Before placing the order for tires, four tire companies (Goodyear, B. F. Goodrich, Firestone, and Michelin) were contacted for their recommendation of the most suitable type of tire available for the expected service conditions. Steel reinforced tires, which are believed to be the most suitable, were not available in the size required (1600-20). The available tire most suitable on the basis of load and speed requirements is the same as those which were originally used on the rear of the machine. The load rating of these tires is less than that required to handle the calculated

maximum weight, but they were procured since no tires of greater capacity were available and since this type has been used successfully. The only alternative to this was to replace the existing rims and planetary hubs with units which would accommodate tires of a larger size. This should be considered for future machines to ensure maximum tire life. Since only one type of tire was available, the selection of tires on the basis of desired compaction could not be done as previously planned.

5. *Overhaul and modification of hydraulic system*--The transmission-mounted dual hydraulic pump was badly worn and replacement parts were installed. The single stage front pump (positive displacement type), also badly worn, was replaced with a variable displacement, compensated pump of larger capacity. The compensated pump was selected to obviate any power loss when its cylinders (claw arm and ejector gate cylinders) were inoperative. The main frame was lengthened to accommodate the new pump.

The hydraulic system valves and valve manifold were removed, disassembled, cleaned and inspected. The valves were satisfactory with the exception of the built-in relief valves, which were worn. Since these valves are no longer manufactured, they were repaired by lapping the seats and plunger. The valves were reassembled and the relief settings adjusted to 1100 lb/in^2.

All hydraulic cylinders were removed, disassembled and inspected. After obtaining comparative cost estimates of overhauling and replacing them, the choice was made to overhaul. During the overhaul the low pressure (150 lb/in.^{2}) galvanized pipe fittings, which were originally welded to the cylinders, were replaced with high pressure (3000 lb/in.^{2}) steel fittings. While the galvanized fittings had functioned satisfactorily, they are not coded for the operating pressure of 1000 lb/in.^{2} and therefore were not used.

The original hydraulic oil filters in the reservoir tank were replaced with finer mesh filters of larger capacity and equipped with visual plugging indicators. They also have a built-in bypass, which functions if the filter clogs, and magnets for trapping magnetic particles. Neither of these features were on the original filters.

6. *Modification of vehicle lighting*--Taillights and stoplights were installed. The existing headlights were rewired.
7. *Modification and repair of structural components*--Cracks at a weak point in the main frame just above the front axle were repaired and the section strengthened by the

addition of 1/2-in. thick stiffening plates. The frame cross bracing in this area was also reinforced.

8. *Renovation of load handling components*--New fabrication drawings were prepared for the box, claw, and claw arm. These components, which were badly worn, were replaced. The original ejector gate was modified to fit the new box.

9. *Modification of control components*--The operator's control turret was rebuilt and a new pilot control system, using "Hydronic" master-slave units, was installed. Individual units control the box, claw, and claw arm hydraulic circuits; the transmission controls (Forward-Reverse, Speed Range, Front Drive Clutch); and the engine throttle (through a foot-operated unit). While this system has improved machine performance somewhat by providing more positive positioning of the primary hydraulic system operating valves, mechanical linkages were preferred, but would have required elimination of the operator's turret.

Evaluation.

Speed Ranges. The Multi-Mover speed ranges were selected originally as a compromise between a maximum speed adequate for highway travel and a minimum speed suitable for earthmoving operations. The resulting minimum speed is somewhat higher than that found in competitive equipment and should be reduced in future models. A transmission with more than three speed ranges will be required if the top speed is to be maintained. Such units are available, but are not physically interchangeable with the present transmission without some redesign of the machine.

Turning Radius. The turning radius of the Multi-Mover is greater than the turning radius for front loaders and wheeled dozers. These units obtain the shorter turning radius because of their articulated design, and incorporation of this feature in the Multi-Mover would require a major redesign. The Multi-Mover does have an additional feature that most other types of units do not have which makes a short turning radius less significant at least in landfill service. This is the capability to operate in either direction with the operator facing in the direction of travel.

Vehicle Clearance. The relatively low road clearance increases the possibility of high centering the machine. However, the ability to raise and lower the box, and hence the machine, affords the operator a means of freeing the machine if high centering should occur. The four-wheel drive capability assists in freeing the machine in the event of high centering.

Hydraulic System. The operation of the hydraulic system could be made more reliable by elimination of the rotating turret. This would permit the direct mechanical operation of the control valves, rather than operating them through a hydraulic pilot control system, resulting in more positive operation of the valves. Another change which would improve the overall reliability would be to use gear type pumps. The close clearances of other type pumps render them susceptible to damage from the pumping of fluid containing very small amounts of particulates. Even extremely fine mesh filters do not always provide sufficient protection. A replacement pump with larger clearances is desirable.

Vehicle Code Compliance. A review of state road and highway regulations was made to assure that the Multi-Mover would comply with these regulations when operating in the highway mode. (See Appendix A.) The review showed that the width of the machine exceeds the maximum allowable width of 8 ft by approximately 6 in. Therefore, the Multi-Mover must have an oversize permit to operate on the highways (Figure 3). A design modification reducing the machine width to 8 ft would be desirable on future models to overcome this limitation.

The machine complies with the requirements concerning weight per axle and minimum speed. The modified braking system complies with the requirements for a dual hydraulic brake system. Installation of taillights and stoplights, in addition to the existing headlights, will provide code lighting.

Operator Protection. Only one state, Michigan, requires an all-weather cab. Since standard cabs will not fit the machine, a specially designed cab would be needed to allow

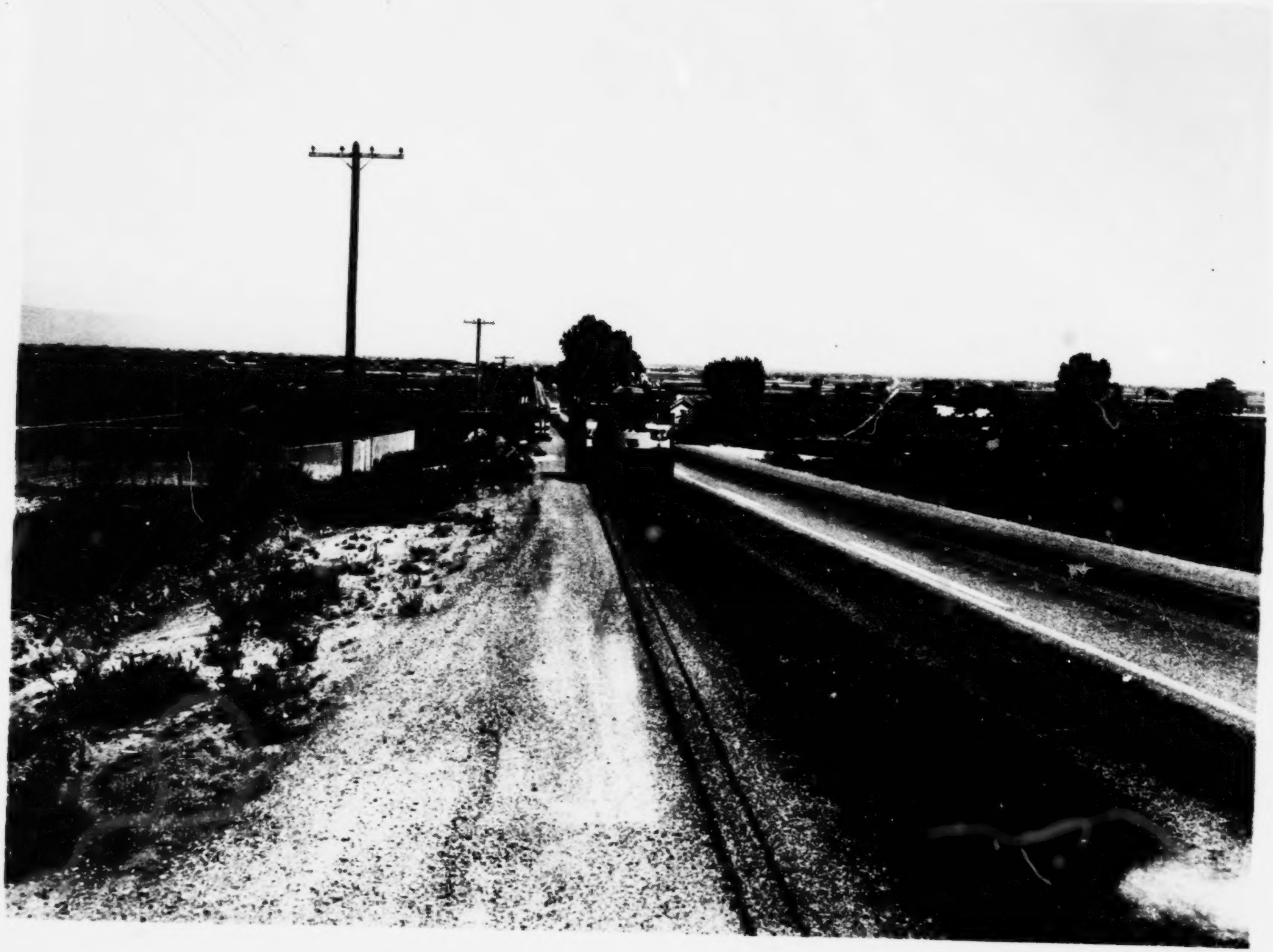

Figure 3. Multi-Mover Traveling on Highway
(Note use of road shoulder to obtain comfortable clearance from highway centerline)

operation in Michigan. This feature is a necessary adjunct to marketing the Multi-Mover as an all-weather machine. A review of options available for competitive machines reveals that the all-weather cab option is widely available.

Phase II -- Field Evaluation and Data Collection

Comparative evaluations of Multi-Mover performance with crawler tractor performance were performed at landfill sites near Nampa, Idaho and Ontario, Oregon. (See Figure 4.) The purpose of these tests was to determine the effectiveness of the Multi-Mover in compacting waste and soil cover material, performing excavation, depositing soil cover, distributing refuse for compaction, and transporting itself from site to site. The compaction tests were performed at the landfill site near Lake Lowell located five miles north of Nampa, Idaho. Earthmoving tests were conducted at the Lake Lowell site, the Ontario site, and the Black Canyon site, while highway transportability tests were conducted between the sites at Central Cove, Black Canyon and Lake Lowell. (The location of these sites is shown in Figure 5.) A special trip was made to Cougar Mountain Lodge, Idaho to evaluate long distance highway travel and operation under winter conditions.

__Data Collection__. Data collection for the field evaluation included measuring and recording the weights or volumes of waste entering a compaction cell, surveying the cells to

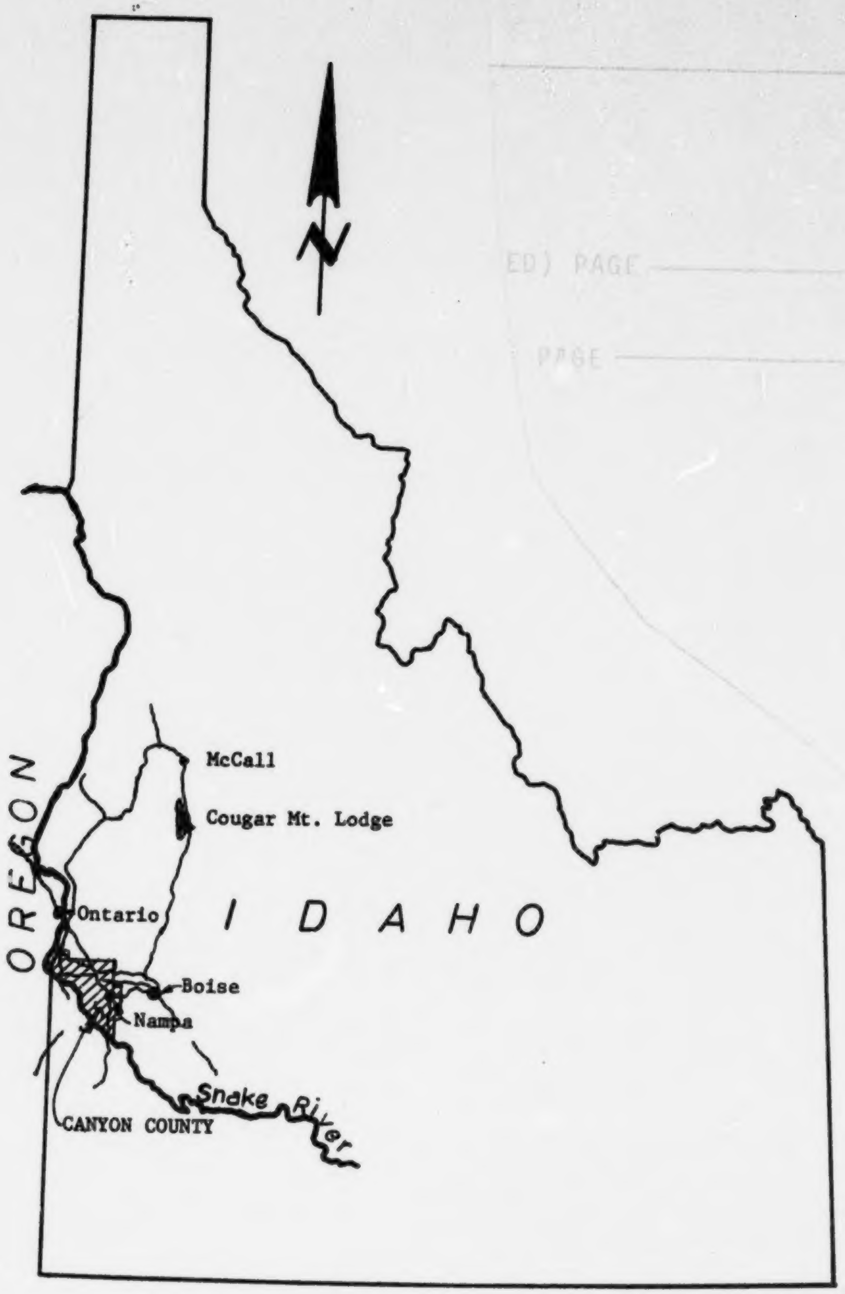
McCall
Cougar Mt. Lodge
OREGON
Ontario
I D A H O
Boise
Nampa
Snake River
CANYON COUNTY

Figure 4. Regional Map of Evaluation Sites

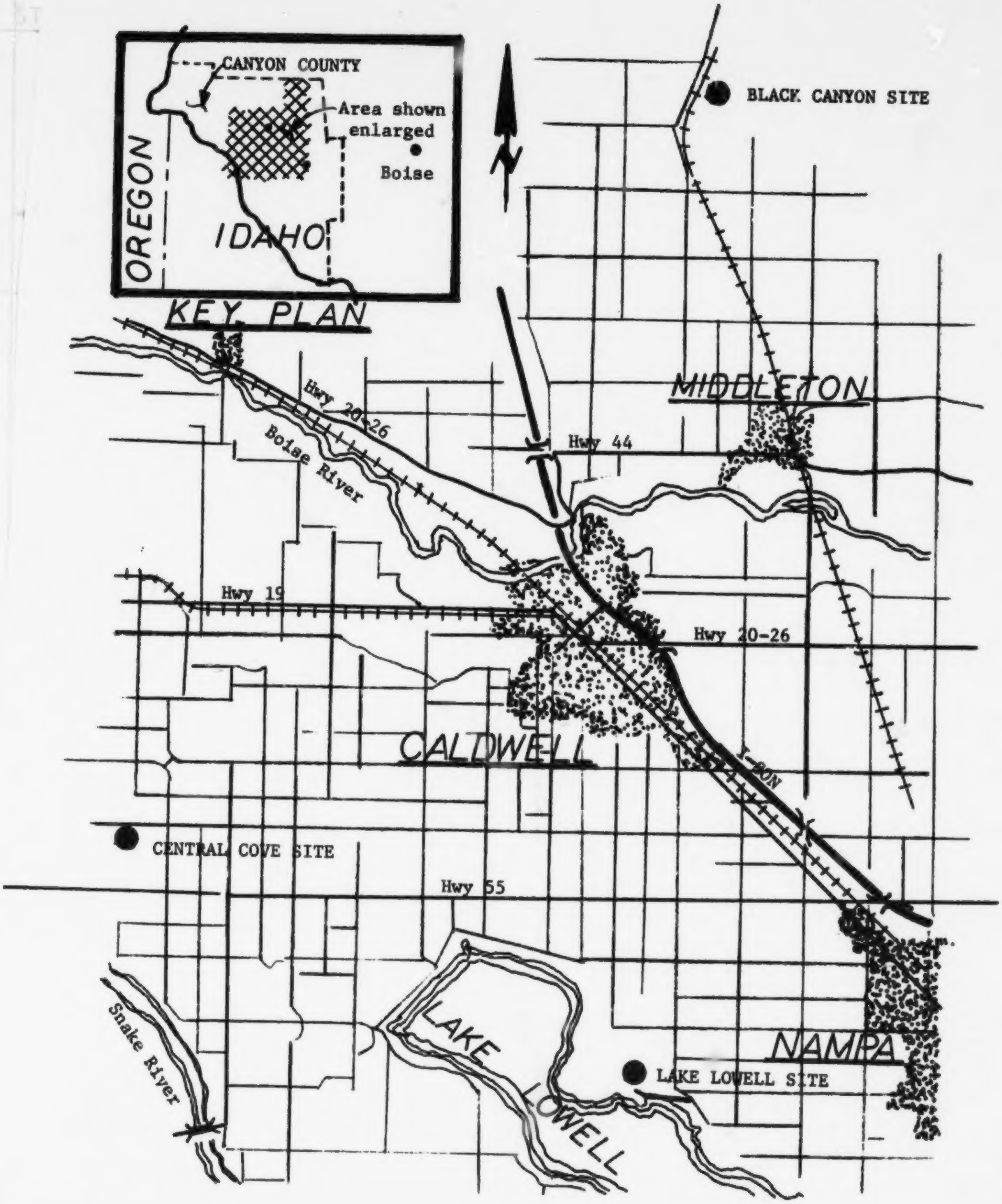
CANYON COUNTY
Area shown enlarged
Boise
OREGON
IDAHO
KEY PLAN
N
BLACK CANYON SITE
MIDDLETON
Hwy 20-26
Boise River
Hwy 44
Hwy 19
Hwy 20-26
CALDWELL
I-80N
CENTRAL COVE SITE
Hwy 55
Snake River
LAKE LOWELL
NAMPA
LAKE LOWELL SITE

Figure 5. Detailed Sites Location Map (Scale: 1"=2 Mi)

obtain data on compacted volumes, timing earthmoving operations and weighing the loads, timing machine operations, recording fuel usage and obtaining other data necessary to provide a basis for machine evaluation. Data collection sheets (Appendix B) were used to selectively obtain the data on refuse weights (or volumes), compaction, earthmoving, highway travel, and fuel and oil usage.

It was originally planned to perform all compaction tests on a volume basis and evaluate the machine on the compaction ratio achieved (trucked volume/in-place volume). However, it was decided to weigh the refuse and obtain compaction data expressed in pounds per cubic yard, a more meaningful figure which would afford a better comparison. Truck scales were used for weighing refuse for the majority of the cells, but before completion of this phase, the scales were destroyed in a fire. After that time, cells had to be evaluated on a volume basis.

Sites Characterization. Evaluation work was performed at three landfills -- Lake Lowell, Black Canyon, and Ontario, Oregon. The Lake Lowell site was operated as an area landfill for the first three cells and later as a ramp type. This site serves a population of about 49,000 Regular equipment consists of two medium size crawler tractors with front end bucket loaders. The climate, being dry and temperate, has little effect on landfill operations; i.e., there are little or no problems from mud or extreme winter conditions. The site is located in gently rolling terrain. It was originally a gravel pit, and at the time of compaction tests on cells L-1, L-2, and L-3, it had nearly been filled. Cover material is readily available and ranges from the silty loam described to a sandy loam with cobble gravel found beneath the cemented hardpan. Table 2 lists data for this site.

The Black Canyon site is operated as a trench-type landfill. It serves a population of less than 5,000 and does not have permanently assigned equipment. The site is located in gently sloping terrain, and has the same climatic conditions as the Lake Lowell landfill. The available cover material is sandy loam in ample supply. Site data is listed in Table 3.

The Ontario site is operated as an area-type landfill in a ravine. It serves a population of about 5,000. Regular equipment consists of one small crawler tractor with dozer blade and one medium size crawler tractor with front bucket loader. The site is located in a ravine, and has the same climatic conditions as the Lake Lowell site. The available cover material is a sandy loam with some cobble gravel. Material is in short supply and must be taken from the steep ravine sides. Site data is listed in Table 4.

Field Evaluation. Field evaluation of refuse handling and compaction effectiveness, consisting of constructing refuse cells with the Multi-Mover and crawler tractors, was done entirely at the Lake Lowell landfill. Earthmoving

TABLE 2

LAKE LOWELL SITE DATA

LANDFILL TYPE:	Ramp
POPULATION SERVICE:	49,000
TOPOGRAPHY:	Gently rolling terrain

CLIMATICS

PRECIPITATION, in./yr	10.6
MEAN TEMPERATURES, °F	50.7 (annual) 65.0 (max) 36.5 (min)
MEAN WIND VELOCITY, MPH	9.0

SOILS

COVER MATERIAL	
Type:	Loam
Texture:	Silty to sandy with 3 in. maximum diameter cobble gravel
Depth:	20 to 36 in.
Availability:	Excellent
Shrink & Swell Potential:	Low to moderate
SUBSTRATE	
Type:	Cemented hardpan

TABLE 3

BLACK CANYON SITE DATA

LANDFILL TYPE:	Trench
POPULATION SERVICE:	5,000
TOPOGRAPHY:	Gently sloping terrain
CLIMATICS	
PRECIPITATION, in./yr	10.6
MEAN TEMPERATURES, °F	50.7 (Annual) 65.0 (max) 36.5 (min)
MEAN WIND VELOCITY, MPH	9.0
SOILS	
COVER MATERIAL	
Type:	Loam
Texture:	Sandy
Depth:	8 ft
Availability:	Excellent
Shrink & Swell Potential:	Low to moderate
SUBSTRATE	
Type	Cemented hardpan

TABLE 4

ONTARIO SITE DATA

LANDFILL TYPE:	Area
POPULATION SERVICE:	5,000
TOPOGRAPHY:	Ravine
CLIMATICS	
PRECIPITATION, in./yr	10.6
MEAN TEMPERATURES, °F	50.7 (annual)
	65.0 (max)
	36.5 (min)
MEAN WIND VELOCITY, MPH	9.0
SOILS	
COVER MATERIAL	
Type:	Loam
Texture:	Sandy with 3 in. maximum diameter cobble gravel
Depth:	N.A.
Availability:	Poor--must be taken from sides of ravine
Shrink & Swell Potential:	N.A.
SUBSTRATE	
Type	Cemented hardpan

evaluations were conducted at Lake Lowell and at the Black Canyon site near Middleton. Highway travel was evaluated by trips between sites and a trip to Cougar Mountain Lodge, where the Multi-Mover was tested for its ability to plow, load, and unload snow, in addition to its general winter operation capability. Waste characterization was performed at the Lake Lowell landfill. The methods used in these characterizations and evaluations and the results are described in detail in the following paragraphs.

Waste Characterization. Waste characterization studies were performed in November 1969, April 1970, and May 1970, to identify the types of waste being handled and to note seasonal variations therein. Classification of wastes was done visually by dumping the compactor truck refuse onto the fill and spreading the loads into layers about 24 in. deep; then the volume percentages were estimated (Table 5).* Categories were defined as suggested by the Bureau of Solid Waste Management.(1) Commercial, residential and industrial wastes were used which are typical of those regularly entering the landfill. The November classification was made on two separate waste cell lifts totalling 138,000 lb; the April classification on 8 compactor truck loads; and the May classification on 24 compactor truck loads.

Inasmuch as the characterizations were visual estimates they can be considered only approximate. Seasonal variations

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* EPA Comment: Visual solid waste classification is not considered to be accurate.

TABLE 5

WASTE CHARACTERIZATION *

Type of Waste	Volume (~ % of total)		
	Nov	April	May
Paper and Paper Products	55.0	48.0	45.0
Food Wastes	15.0	14.0	14.0
Metal	4.0	5.0	4.0
Glass	2.0	5.0	3.5
Bulk Leaves and Grass	3.0	5.0	6.0
Wood	8.0	15.0	15.0
Plastics	5.0	3.5	3.5
Cloth, Rubber, Leather and Synthetics	6.0	3.0	7.0
Dirt, Ashes, Rocks	2.0	1.5	2.0

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* See EPA Comment on page 45.

apparent in Table 5 are also approximate. The most significant seasonal variation which affected the compaction operation in April and May were the larger amounts of bulk leaves, grass, and wood, which compact less than the other wastes. This was particularly noticeable with discarded plywood panel trimmings from a local mobile home manufacturer.

Landfill Performance. Tests were conducted to evaluate Multi-Mover performance compared to that of a crawler tractor in compacting waste and soil cover, spreading refuse, excavating and hauling earth, spreading earth cover, and highway travel. These tests are described and the results are given as follows:

1. *Compaction comparisons*--Compaction comparisons were made by constructing refuse cells of varying sizes at the Lake Lowell landfill separately with the Multi-Mover (27,225 lb unladen) and crawler tractor No. 1 (33,757 lb unladen). Crawler tractor No. 1 was used on cell L-2 equipped with a 1-1/4 yd front loader bucket. For cell L-6, crawler tractor No. 2 (21,000 lb unladen) with a 1-1/4 yd front loader bucket was used. A total of eight compaction cells were constructed (Figure 6). For each cell, a baseline was established, elevations were taken on the baseline, and preliminary cross sections were taken with a builder's level-transit and hand level at 20 ft intervals. Except for cells L-1 and L-2, intermediate and final cross sections were taken at intermediate

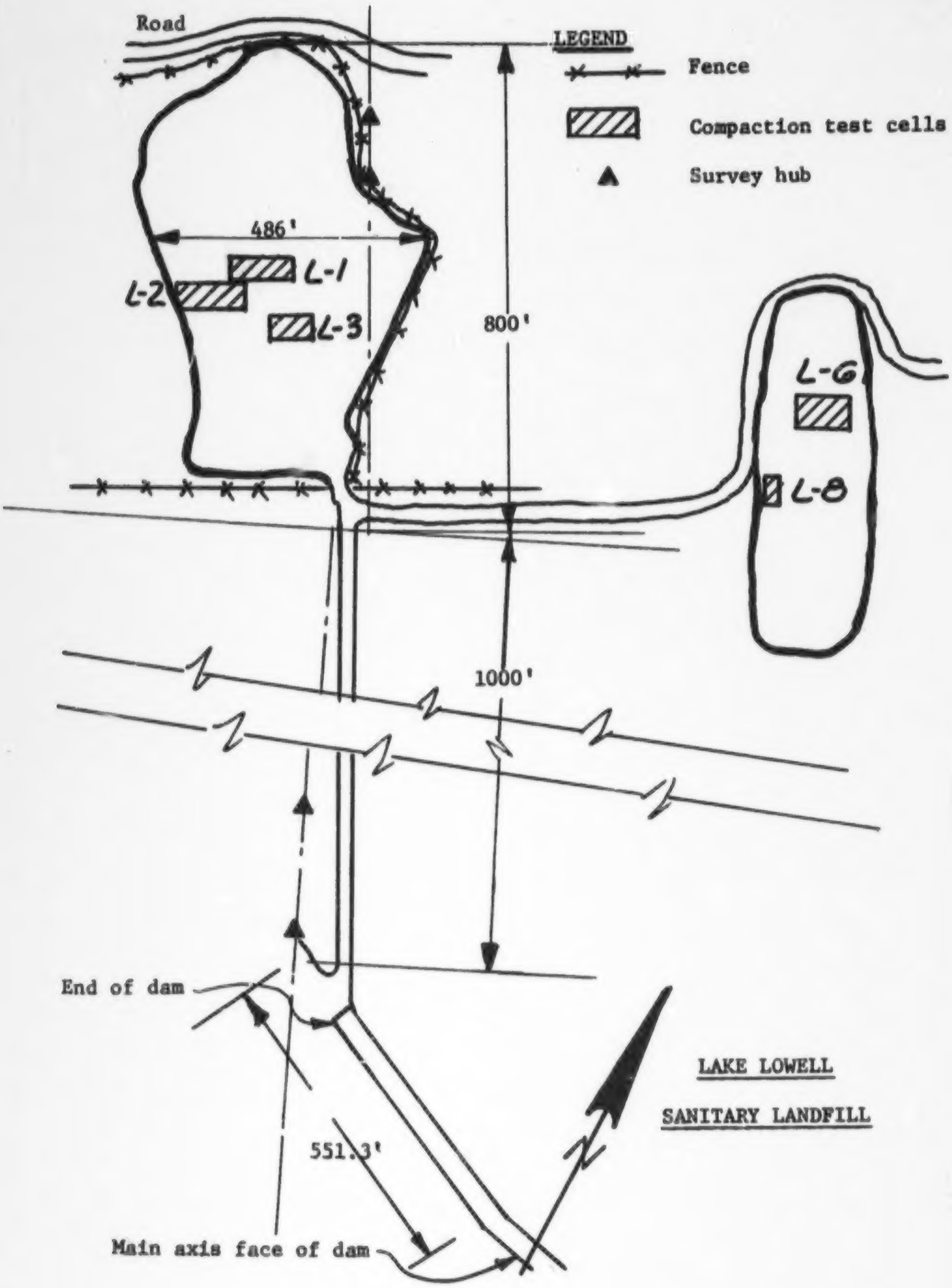
Road
LEGEND
Fence
Compaction test cells
Survey hub
486'
L-1
L-2
L-3
800'
L-6
L-8
1000'
End of dam
551.3'
Main axis face of dam
LAKE LOWELL
SANITARY LANDFILL

Figure 6. Lake Lowell Compaction Cell Location

lifts, the top of the cell before addition of cover, and the top of the cell after cover addition. On cells L-1 and L-2 final cross sections were taken only after cover addition. Volumes were calculated using the average end area method.

Crawler tractor cells L-2 and L-6 and Multi-Mover cells L-1, L-3, and L-8 were completed without incident. Cell L-8 was constructed using water to improve compaction. However, varying circumstances rendered data unusable on three other cells. Cell L-4 was nearly completed by the crawler tractor when an extended breakdown of the tractor prevented its completion. Settlement and traffic compaction during the repair period rendered that data unusable. Through a misunderstanding the surface of cell L-5 on which the crawler-tractor-compacted cell was to be built was excavated to obtain cover soil and filled with waste, thus negating the original survey. During construction of cell L-7 by the Multi-Mover, the Multi-Mover lost engine power and was unable to negotiate the slopes of the ramp type cell. Consequently, the cell received minimum compaction, and when the machine lost power completely, the cell had to be completed with a crawler tractor.

Cells L-1, L-2, L-3, and L-6 averaged 3 to 4 ft in thickness, and the maximum thickness was 4-1/2 ft. To determine the settlement of the surface on which the cell was constructed (the top of the existing landfill), settlement gages were employed. Measurements by level-transit of elevations of the top of these gages, placed at 50 ft intervals on the centerline of cell L-1, showed that for a cell of this thickness the settlement was 0.05 ft. This was judged negligible considering that the accuracy of a hand level used for a portion of the cross section surveys was ±0.10 ft. Because of this small settlement, the use of gages was discontinued for the other cells.

For cell L-8, constructed June 4, 1970, the Multi-Mover compacted 96 yd^3 of packer truck residential refuse in two lifts of 48 yd^3 each, using water and two compaction passes per lift to improve compaction. The refuse for this cell was classified as follows:*

Waste	Approx. % by volume
Paper and paper products	55
Food wastes	15
Metal	4
Glass	5
Bulk leaves & grass	5
Wood	5
Plastics	5
Cloth, rubber, leather, and synthetics	4
Dirt, ashes, & rocks	2

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* See EPA Comment on page 45.

A summary of compaction data for cells constructed dry is given in Table 6. Table 7 lists data derived from cell L-8. Compaction ratios (trucked volume/in-place volume) obtained on cells L-1, L-2, L-3, and L-6 under dry conditions are listed in Table 8.

As shown in Tables 6 through 8, the Multi-Mover can accomplish a relatively high density of compaction in a landfill. With four compaction passes* per lift it was able to achieve an in-place waste density of 1178 lb/yd^3. In comparison to crawler tractor No. 1 and using one compaction pass per lift, it achieved an in-place waste density of 906 lb/yd^3, where the tractor achieved 1015 lb/yd^3. In constructing cells L-1 and L-2, all the wastes entering the landfill were placed in the cells. Hence, waste agricultural seed was used along with the normal commercial, residential, and industrial wastes. The high density of these seeds, about 960 lb/yd^3, contributed to relatively high compacted waste densities in both cells. The greater percentage of waste seed in the crawler tractor cell, 15.4% by weight versus 9% in the Multi-Mover cell, gave a higher

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*One compaction pass consisted of passing the front and rear tires (or tracks of the crawler tractor) one time over the entire surface of a cell.

TABLE 6

COMPACTION DATA SUMMARY FOR CELLS CONSTRUCTED DRY

	Cell Number(1)			
PARAMETER	L-1	L-2	L-3	L-4
Equipment Used	Multi-mover (27,225 lb.)	Crawler Tractor No. 1 (33,757 lb.)	Multi-mover (27,225 lb.)	Crawler Tractor No. 2 (21,000 lb.)
Type of Landfill	Area	Area	Area	Ramp
Cell Size, ft	50 x 110 x 3.5	60 x 155 x 3.5	50 x 78 x 2.5	45 x 90 x 4
Waste Lift Depth, Loose, in.	12	12	24, 96, 12	36
No. of Waste Lifts	7	6	3	3
Water Added	None	None(2)	None	None
No. of Compaction Passes/Waste Lift	1	1	4	3
Total wt. of Waste, lb.	260, 180(3)	535, 990(3)	137, 960	214, 960
Compacted vol. of Waste, yd^3(3)	287.2	528.0	117.1	356.6
In-Place Waste Density, lb/yd^3(4)	906	1015	1178	603
Waste Density by USPHS Formula lb/yd^3 (5)	679	766	758	508
Cover Lift Depth, Loose, in.	8	6	8	6
Cover Lift Depth Compacted, in.	6	6	6	6
Total Compacted Vol. of Waste + Cover, yd^3	383.3	700	182.1	423.2
Weight of Soil Cover, lb. (calculated)	288,000	455,800	230,000	191,750
Total In-Place Density Cover + Waste lb./yd^3 (6)	1430	1417	2021	961

Footnotes itemized on the following page

TABLE 6 (continued)

Footnotes for Table 6

(1) Data for Cells L-4, L-5, and L-7 not noted and not shown.

(2) Cell L-2 received about 0.10 in. of rain. This added moisture assisted in obtaining compaction somewhat higher than might normally be obtained with the crawler tractor.

(3) Cell L-1 contained 23,300 lb. of waste agricultural seed. Cell L-2 contained 82,600 lb. of waste agricultural seed. This material weighed approximately 960 lb./yd^3, loose.

(4) In-place densities and compacted volumes of waste were calculated from data taken after placing soil cover.

(5) The formula recommended by the USPHS for waste density is

$$\frac{\text{wt. of refuse}}{\text{vol. of refuse + vol. of soil}}$$

When a significant percentage of the total volume is soil as in these relatively thin cells, this waste density is disproportionately low. This is particularly noticeable in Cell L-3 where the soil volume is 65 yd^3 compared to 117.1 yd^3 of refuse.

(6) These total in-place density figures will be higher than normally obtained in most land fills because of the relatively thin cells (3 to 4 ft thick for Cells L-1 and L-2, 2 ft thick for Cell L-3). The weight of cover material in these thicknesses is often greater than the weight of refuse, which results in a high total density.

TABLE 7

MULTI-MOVER COMPACTION CELL L-8 - WATER ADDED

PARAMETER	Lift 1		Total Cell Lift 1 + Lift 2	
	Dry	Wet	Dry	Wet
Total Uncompacted Refuse, yd^3	48	48	96	96
No. of Compaction Passes/Lift	2	2	2	2
Total Passes	2	4	6	8
Amount of Water Added,(1) gal/yd^3	None	7.15	None	14.3
Volume of Compacted Refuse, yd^3	16.8	14.46	29.45	21.8
Compaction Ratio(2) *	2.86:1	3.32:1	3.02:1	4.4:1

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(1) Average of water added for both lifts is 10.7 gal./yd^3

(2) The compaction ratios for the total cell are calculated on the combined volumes of Lift 1 and 2. The compaction ratios for Lift 2 alone are 3.20:1 (dry) and 6.54:1 (wet). However, these figures are not representative because there was further compaction of Lift 1 during Lift 2 construction. Therefore, the average for the combined lifts is shown.

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*EPA Comment: Since the density of solid waste in collection vehicles may vary considerably, compaction ratios would yield only very gross comparisons of the compaction capabilities of landfill equipment.

TABLE 8

COMPACTION RATIOS OF CELLS CONSTRUCTED DRY

	Cell No.			
PARAMETER	L-1	L-2	L-3	L-6
Equipment Used	Multi-Mover	Crawler Tractor No. 1	Multi-Mover	Crawler Tractor No. 2
Trucked Waste Vol., yd^3 (1)	750	1463	495	733
Compacted Waste Vol., yd^3	287.2	528.0	117.1	356.6
No. of Passes Per Lift	1	1	4	3
Compaction Ratio *	2.6:1	2.8:1	4.2:1	2.1:1

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(1) Trucked volume is the rated volume capacity of the compactor trucks, which deposited 95% of the waste in these cells. Thus, the waste had some pre-compaction.

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* See EPA Comment on Page 54.

than normal density in the crawler tractor cell. Considering that the tractor cell, L-2, had the benefit of rainfall to assist compaction and a higher percentage of waste seed, it would appear that the Multi-Mover (27,225 lb) is approximately equivalent to the heavier tractor (33,767 lb) in compactive effort when using one pass per waste lift in an area-type landfill.

When the compaction of the Multi-Mover from multiple passes (four) on an area fill is compared to that of a lighter (21,000 lb) crawler tractor using 3 passes per lift on a ramp-type fill, the Multi-Mover yields a compacted waste density nearly two times as great, 1178 lb/yd^3 versus 603 lb/yd^3. However, the differing conditions (particularly with the lighter tractor and under ramp cell conditions) where the material tends to roll under the tracks rather than compact vertically, tended to give the Multi-Mover an unfair advantage in this comparison.

Observations made in the field indicated that the compactive effort of the Multi-Mover was markedly better than either of the crawler tractors used. The Multi-Mover tires would compact up to one-third the original depth of a loose waste lift in one pass with little springback, whereas the crawler tractor would compact to about one-half the depth with springback of the upper loose materials to nearly the original level.

The data in Table 8, which summarizes the compaction ratios,* indicates that under dry conditions the Multi-Mover compacts somewhat less than a heavier crawler tractor, 2.6:1 versus 2.8:1, on an area-type fill with single pass compaction per lift. Again, the larger amount of waste seed and the moisture from the rain in the crawler tractor cell contributed to a density and compaction ratio higher than normal for the crawler tractor. With multiple passes, the Multi-Mover can achieve a compaction ratio of 4.2:1. As shown in Table 7, when water is deliberately added, compaction ratios as high as 4.4:1 can be achieved in two passes per waste lift. On a dry, ramp-type cell, the 21,000 lb crawler tractor achieved a compaction ratio of 2.1:1 with 3 compaction passes per waste lift. In other tests, measurements made during area-type cell construction showed compaction ratios of 3:1 in four passes of the Multi-Mover on 24 in. lifts of compactor truck refuse. The 33,757 lb crawler tractor produced a compaction ratio of 2:1 under these conditions.

2. *Distributing refuse for compaction*--The Multi-Mover was able to move large amounts of light, loose wastes better than crawler tractor No. 1, moving 15 to 30 yd^3

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* See EPA Comment on Page 54

of waste at one time compared to 6 to 8 yd^3 for the crawler tractor. However, in soil moving, as a dozer, they were about equal, and when large heavy loads were encountered under poor traction conditions, the crawler tractor was clearly superior.

In spreading and compacting the wastes (Figure 7), the Multi-Mover did not perform as uniformly as either crawler tractor. Because of the 10 in. clearance above the fill, the machine caught refuse already spread and rolled it ahead. The operator was often unaware of this since the box and ejection gate obstructed his view of the area directly in front of the machine. On the crawler tractor, the front end loader could be lifted several feet to clear and spread the wastes and visibility was better. This tendency to catch refuse contributed to the Multi-Mover achieving lower actual compaction than it was capable of achieving, and left the fill surface uneven. This was judged to be the most serious shortcoming of the Multi-Mover in compacting refuse. The Multi-Mover did spread wastes faster than the crawler tractor, achieving a spreading rate of about 6 yd^3/min compared to 4.2 yd^3/min for crawler tractor No. 1. The higher rate of the Multi-Mover is due to its ability to move a larger amount of waste at one time and its higher speed in the low gear range used in spreading.

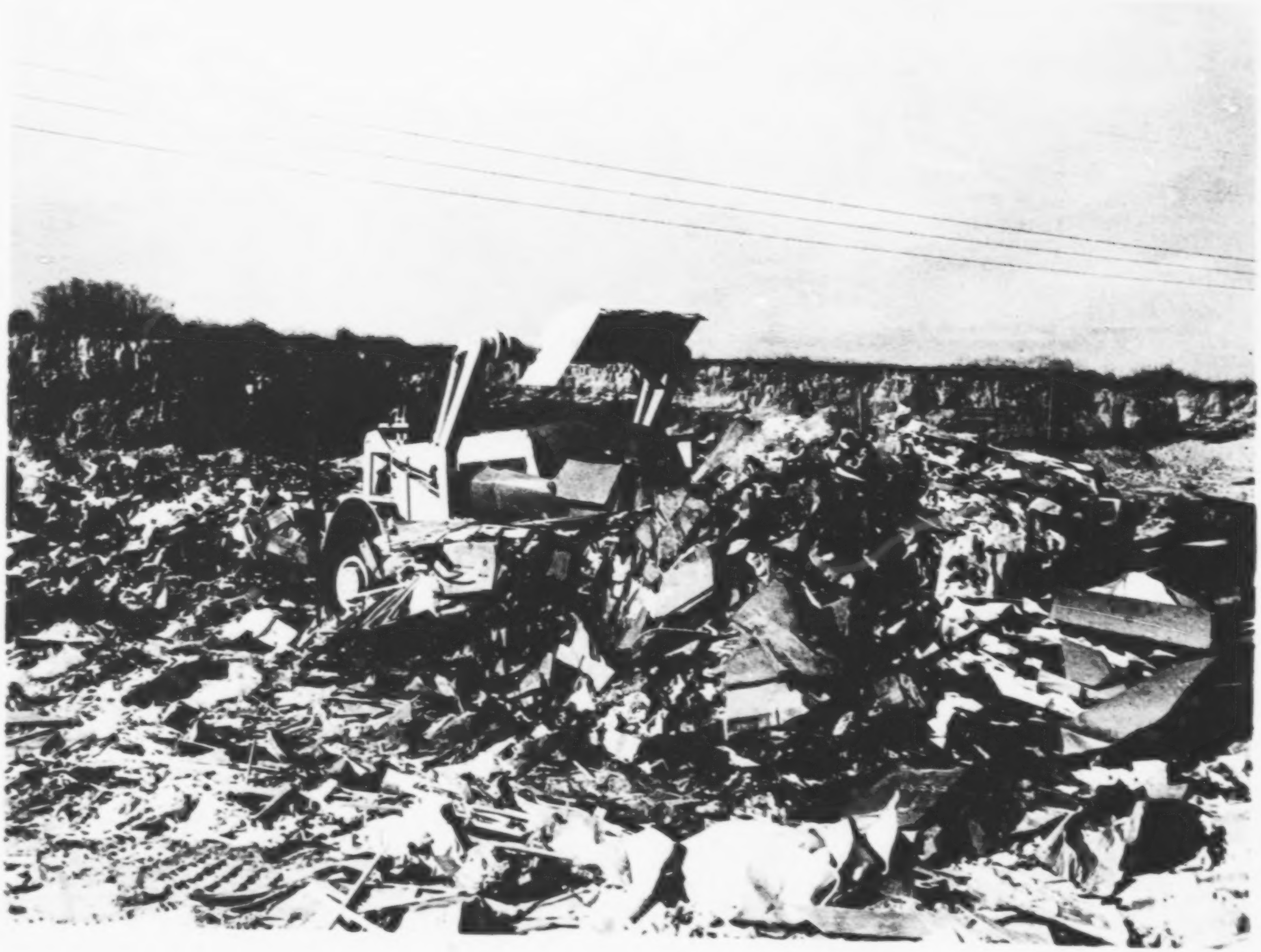

Figure 7. Multi-Mover Spreading Waste for Compaction

3. *Depositing soil cover*--In depositing soil cover (Figure 8) the Multi-Mover achieved approximately the same spreading rate as crawler tractor No. 1 with front bucket loader. This rate was about 0.05 yd^3/sec. The Multi-Mover spread 2-1/4 to 3 yd^3 in 45 to 50 sec and the crawler tractor spread 1 to 1-1/4 yd^3 in 15 to 25 sec. Uniformity of cover thickness as spread by the Multi-Mover was better. By controlling forward speed and ejection gate speed, a fairly uniform layer 6 to 8 in. thick and 4 ft wide could be deposited. The crawler tractor spreading was controlled by tractor speed and rate of bucket tipping. Because the soil tended to hang together until the angle of repose was exceeded, it tipped out unevenly and the resulting layer varied from about 2 to 6 in. in thickness and 6 to 8 ft in width.

4. *Excavation and earthmoving*--Tests were performed to compare excavation and earthmoving from a vertical bank at the Lake Lowell site. Table 9 lists the results of this comparison. Multi-Mover loading time from a vertical bank or stockpile is comparatively slow. As the machine moves into a stockpile the front wheels climb the slope and raise the box and claw above the point where efficient loading can be accomplished. In contrast, the crawler tractor bucket loads very quickly under these conditions because it is well ahead of the tracks.

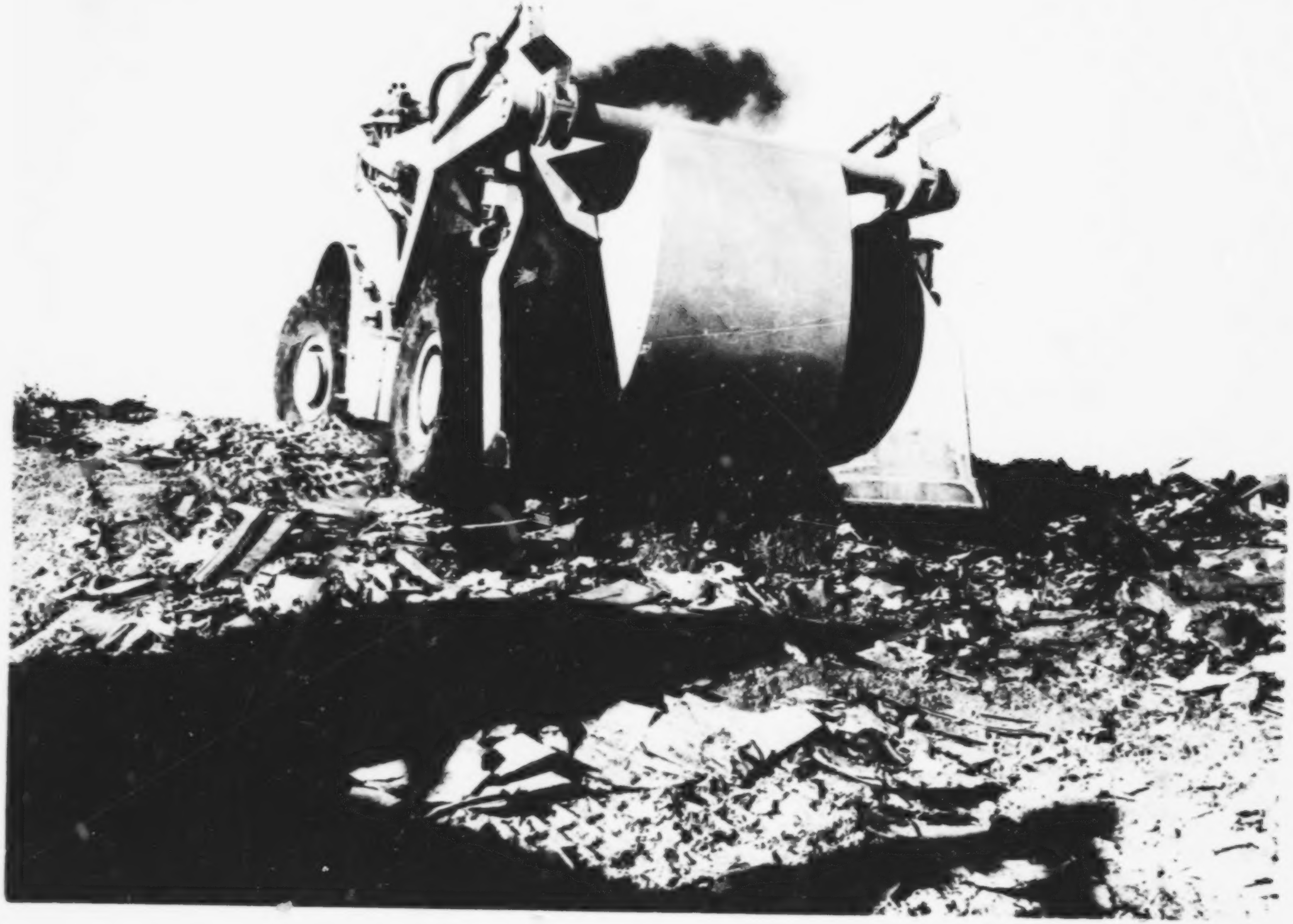

Figure 8. Multi-Mover Depositing Soil Cover Over Compacted Cell

TABLE 9

LOADING, TRAVEL AND UNLOADING TIMES - COVER MATERIAL

	Multi-Mover		Crawler Tractor No. 1	
OPERATION	(yd^3)	(sec)	(yd^3)	(sec)
Loading from Vertical Bank	2-1/4	60	1-1/4	20
Travel Time Per Cycle, 240 ft Haul Each Way		180		200
Unloading Time-Spreading	2-1/4	45 to 90*	1-1/4	15 to 25*
Total Time/Cycle		280 to 330		235 to 245
Seconds/yd^3 in Place		127 to 147		188 to 196

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[*] Differences in unloading time reflect difference in time required to spread a 4-in. thick layer compared to an 8-in. thick layer.

In excavating tests on level ground (Figure 9), excavating sandy loam cover material, the Multi-Mover was able to load 2-1/2 yd^3 in 45 sec. Loading to 3 yd^3 required 90 sec and loading to 4-1/2 yd^3 required 5 min.

The tests indicated that for a haul distance of about 60 ft, loading cover from a bank or stockpile, the crawler tractor outperformed the Multi-Mover because of the crawler tractor's shorter loading and unloading times. For longer haul distances, over about 60 ft, the Multi-Mover outperformed the crawler tractor because of its faster travel.

For a test of excavation ability, the Multi-Mover and crawler tractor No. 3 (19,325 lb unladen) were taken to the Black Canyon site where an area had been excavated to a dense hardpan material. The crawler tractor equipped with a 1-1/4 yd front bucket having ripper teeth was unable to excavate this material at all, there not being sufficient traction for the flat-type tracks. (The heavier crawler tractor No. 1 was scheduled for this test, but was under repair.) The Multi-Mover excavated a trench approximately 4 ft deep by 12 ft wide by 50 ft long in this material in 3 hr. The amount of material excavated, as measured by survey of the deposited material, was 107 yd^3 for an average excavation rate of about 35 yd^3/hr of dense, cemented hardpan.

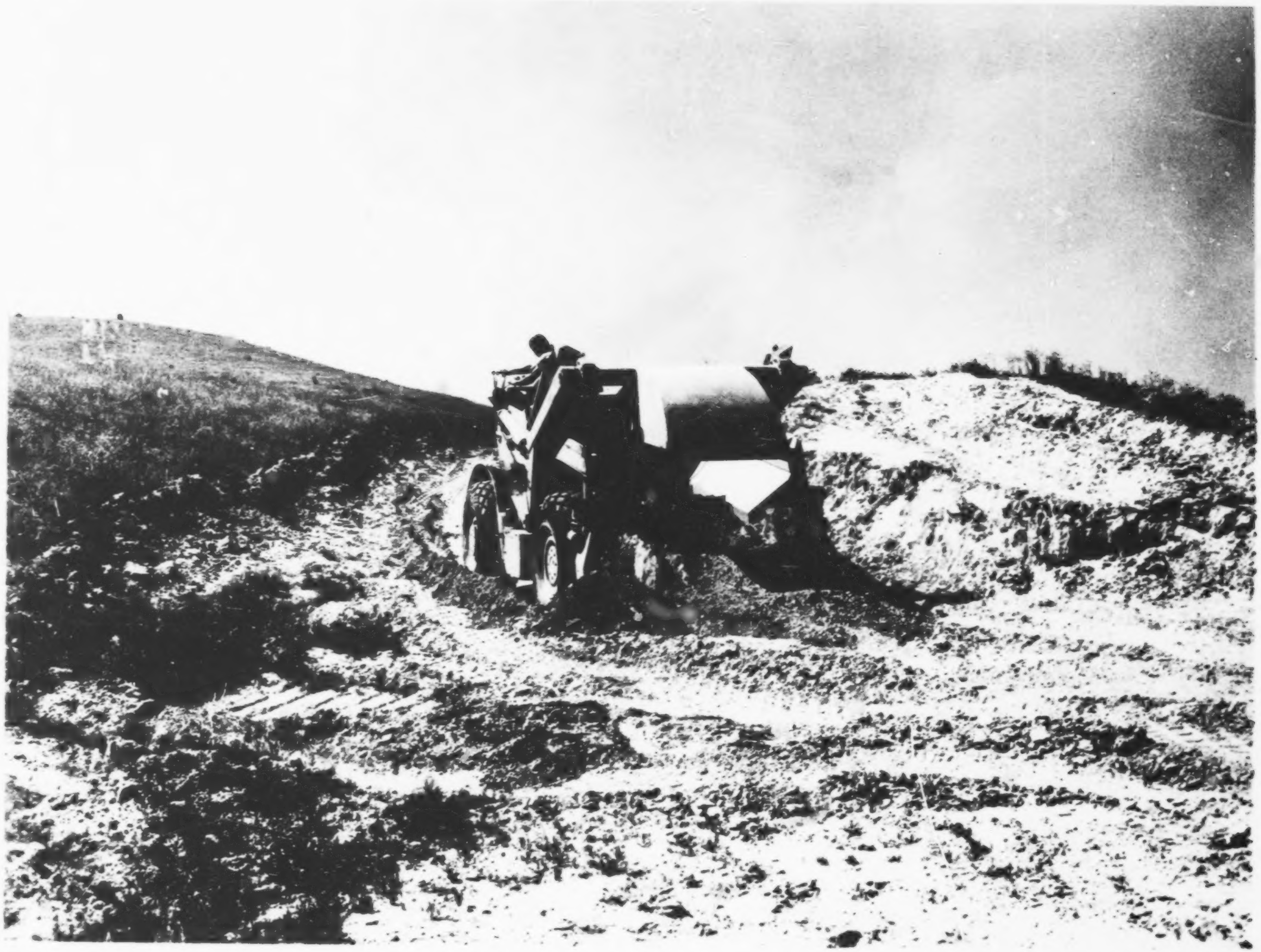

Figure 9. Multi-Mover Performing Excavation at Black Canyon Site

5. *Speed, maneuverability, and handling*--The Multi-Mover speeds on level ground were the same for loaded (3 yd^3, 7500 lb) and unloaded conditions as shown below:

Maximum at 2400 RPM		Average at 2200 RPM on Landfill	
1st gear (Fwd and Rev)	3.9 mph	1st gear	3.0 mph
2nd gear (Fwd and Rev)	9.5 mph	2nd gear	6.2 mph
3rd gear (Fwd and Rev)	30 mph	3rd gear	not used

Maneuverability of the Multi-Mover for most landfill operations was good because its direction could be reversed immediately and it could travel at the same speeds in forward and reverse for spreading and compacting operations. For right angle turns during highway travel or for instances where the machine was turned around on the landfill, maneuverability was poor. The turning radius is 39.5 ft to the left and 56.5 ft to the right. This requires a large clear space to complete a turn on a landfill and a wide swing to complete right angle turns during highway travel without backing up.

Generally the Multi-Mover has the good low speed control needed for landfill service. Speeds over about 8 miles per hour on an uneven surface gave an uncomfortable ride and bouncing action because of the heavy, stiff springs; otherwise, the machine gave an acceptable ride.

Speeds for crawler tractors at rated governed RPM were as follows:

Crawler Tractor No. 1 with 1-1/4 yd Bucket Loader-Unloaded

Gear	Forward (MPH)	Reverse (MPH)
1st	1.5	1.8
2nd	1.9	2.3
3rd	2.5	3.2
4th	3.3	4.1
5th	4.3	5.3
6th	5.8	7.1

Crawler Tractor No. 2 with 1-1/4 yd Bucket Loader-Unloaded

Gear	Speed (MPH)
Low Reverse	2.0
High Reverse	4.1
1st	1.5
2nd	2.4
3rd	3.3
4th	5.5

Crawler Tractor No. 3 with 1-1/4 yd Bucket Loader

Gear	Speed-Unloaded (MPH)	Speed-Loaded, yd^3 2500 lb (MPH)
Low Reverse	1.75	1.75
High Reverse	3.4	3.4
1st	1.62	1.62
2nd	2.27	2.23
3rd	Inoperative	Inoperative
4th	4.01	3.78
5th	5.68	3.68

Maneuverability of the crawler tractors for landfill service was very good since they were able to both reverse and turn in their own length by stopping one track and powering the other. Regulations prohibit highway travel with the crawler tractors under their own power; however, their low speed makes this an uneconomical long distance travel mode. Any speed over about 3 miles per hour on an uneven surface produced a rough, uncomfortable ride. The crawler tractors were easily started and responded well to the controls.

6. *Highway travel*--Highway travel of the Multi-Mover was evaluated in comparison to the crawler tractors, which required trucking, by separate trips to the Central Cove and Black Canyon landfills. These data are summarized in Table 10.

In other highway travel the Multi-Mover was driven from Nampa to Cougar Mountain Lodge, Idaho and back. On that trip the following data were obtained on highway travel:

Total distance traveled (hill & mountains, dry highway)	164 miles
Maximum speed attained	30 mph
Average speed	18 mph
Actual travel time, 164 miles	9 hr
Average fuel consumption	3.36 gal/hr
Mileage (includes fuel used for snow work and idling during stops)	3.5 miles/gal
Tire wear	1/16 in. on front tires. None on rear tires.

TABLE 10

HIGHWAY TRAVEL--MULTI-MOVER VERSUS CRAWLER TRACTOR

PARAMETER	Multi-Mover		Crawler Tractor on Low-Boy	
One-Way Distance	12 miles	15 miles	12 miles	15 miles
Shortest Time, One-Way	1 hr 3 min	1 hr 3 min	1 hr 3 min	1 hr 5 min
Total Round-Trip Time	2 hr 9 min	2 hr 30 min	2 hr 12 min	2 hr 10 min
Load-Unload Time	0	0	23 min	25 min
Average Travel Speed, MPH	11.2	12	10.9	13.8
Total Cost(1)	$ 19.92	$ 24.90	$ 63.86	$ 63.73
Cost/Mile	$ 0.83	$ 0.83	$ 2.66	$ 2.12

---

(1) Includes $ 52.00 fee for lowboy rental to move tractor, operator's time, equipment depreciation and fuel.

While the maximum speed attainable is 30 mph, slow steering response while traveling downhill and stiff, undamped springing dictated a safe maximum speed of about 20 mph. The large turning radius required extra care while maneuvering sharp corners. In general, the machine performs well in highway travel; braking is good and steering is smooth at the recommended safe maximum speed. On short trips of 5 to 30 miles, fuel consumption was 3.0 miles per gallon.

7. *Snow removal*--While at Cougar Mountain Lodge, during April 1970, the Multi-Mover was used to plow, load, and unload snow (Figure 10). Operations was good even though heavy spring snow conditions prevailed. The machine easily loaded, unloaded, and plowed snow. Plowing was hindered by lack of traction where snow over slick ice was encountered. When traction was lost, the machine regained mobility by using the claw to back out and resume plowing. Sufficient wheel clearance for the mounting of chains to improve traction under these conditions would have been beneficial.

8. *Miscellaneous observations of machine performance*--During the field evaluation of the Multi-Mover the following general observations on the machine performance were noted:

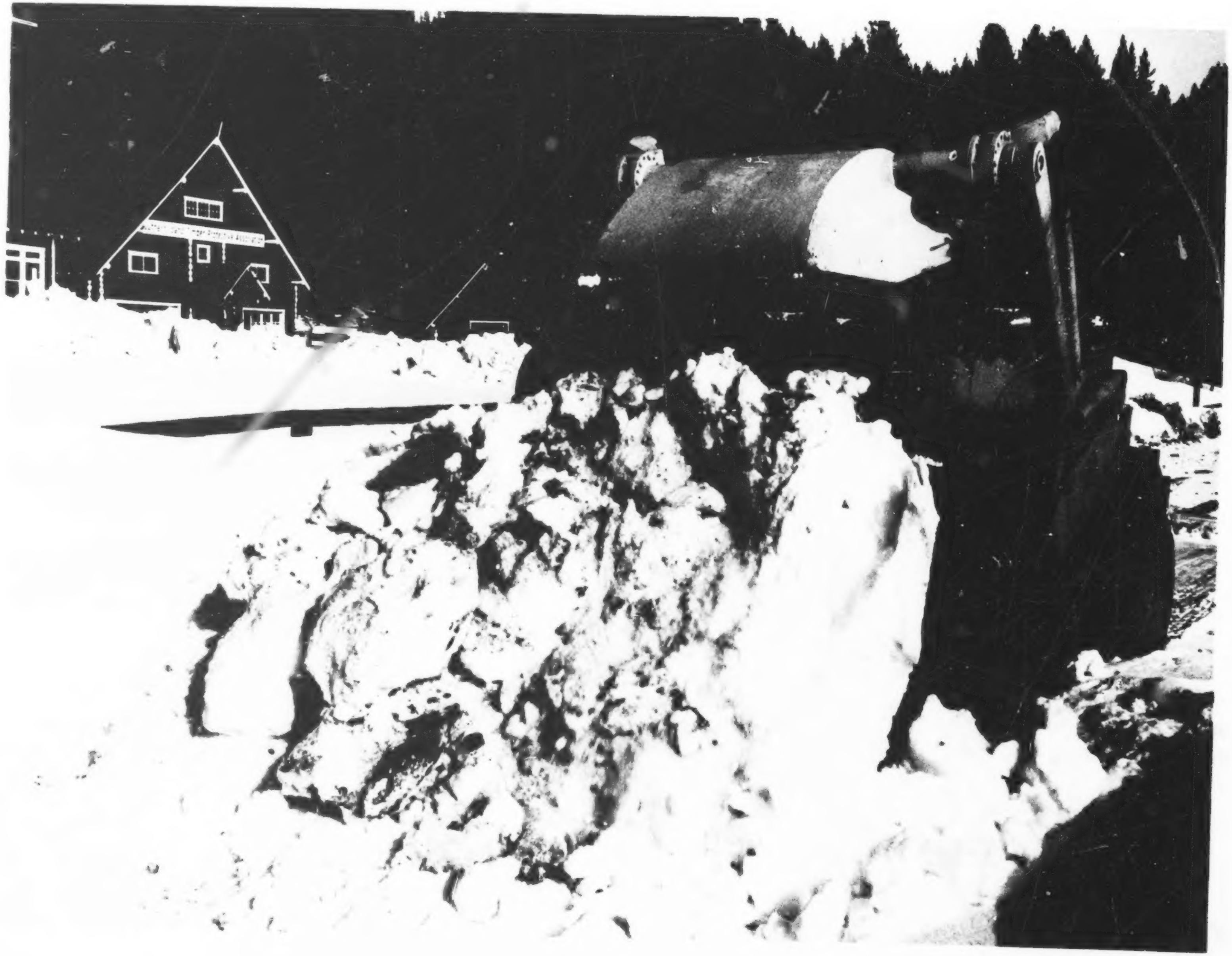

Figure 10. Multi-Mover Performing Snow Removal Operations Near Cougar Mountain Lodge, Idaho

a. Until protected with guards, the universal joints would readily pick up discarded wire on a landfill, which would foul the drive shaft. After guards were installed, no further problems were experienced with wire.

b. The tires were considerably abraided by glass and sharp metal in the refuse. Cuts in the tread up to 1/2 in. deep were observed, but they did not cause flat tires or noticeably impair tire function or traction. One flat tire was experienced from puncture by a large nail.

c. Several hydraulic leaks developed in difficult-to-reach areas. These leaks were never completely stopped. Similar leaks occurred in hydraulic equipment on the crawler tractors but were generally more accessible for repair.

d. The Multi-Mover was able to move and compact large amounts of waste rapidly. During a period when the crawler tractors were undergoing repair, the Multi-Mover was used to move approximately 1475 yd^3 of refuse and compact it in a 10,000 ft^2 area in 1-1/2 hr. During this operation the Multi-Mover routinely moved several loads of refuse up to 30 yd^3 each approximately 300 ft across loose refuse that was 6 to 7 ft deep. In contrast,the crawler tractors were able to move only about 6 to 8 yd^3 under these conditions.

e. The Multi-Mover had good traction on loose refuse. Although it could no doubt be stuck under some conditions (as can a crawler tractor), it did not get stuck during the performance evaluations.

f. The position of the operator is such that he cannot see the cutting depth of the blade on the box. This made it difficult to do good grading work.

g. The Multi-Mover loaded most efficiently on level runs. The design of the machine favors this operation over loading from a stockpile.

h. The exhaust stack temperature limitation (1350 °F max.) prevented steady use of the engine at the rated 2400 rpm. Operation for over a few minutes generally had to be done at 1900 rpm. This prevented use of full engine power.

i. The transmission had a tendency to overheat when subjected to more than about 1/2 hr of heavy work. The transmission is an older model with a small oil cooler, using the engine radiator fluid for cooling by convection flow. Later models of this transmission are equipped with separate oil cooling radiators.

Operating Costs. Data obtained on fuel consumption usage and other operating cost data for the Multi-Mover are incorporated and evaluated in the systems analysis section of this report.

It should be pointed out that data obtained on the repair costs of both the Multi-Mover and the crawler tractors were higher than would be normally incurred for equipment of these types. Both crawler tractors involved in the majority of the comparison testing were older models in poor condition and consequently required maintenance at a higher than normal rate. They were under repair or awaiting parts for repair approximately 50% of the time. Use of this costing data would not provide realistic cost projections typical of crawler tractor operations. Instead, typical maintenance costs of crawler tractors obtained from equipment maintenance were utilized as discussed in the section on systems analysis. The Multi-Mover, though overhauled at the start of the project, was not restored to completely new condition. The original transmission and engine, for example, though worn, were indicated to be capable of performing satisfactorily during the test period. The total repair costs on the Multi-Mover from October 1969 to October 1970 were $7,522. The major items of repair were:

1. Overhaul of the transmission (required removing the box from the frame of the machine).
2. Replacing front hydraulic pump.
3. Replacing cracked engine head including new firing cups.
4. Repairing fuel injector line leaks.
5. Cleaning plugged fuel injector lines.

6. Replacing transmission oil seal.
7. Adjusting ejection gate and hydraulic divider valve to gate cylinders.
8. Repairing broken hydraulic hose.
9. Repairing broken weld on claw arm.
10. Repairing flat tire.
11. Rewiring and repairing battery charging circuit.
12. Repairing miscellaneous hydraulic leaks.

Many of these Multi-Mover maintenance costs were unusual, not representative -- particularly the complete transmission overhaul, replacement of the front hydraulic pump, replacement of the cracked engine head, and repairs and cleaning of the fuel injection lines. Again, maintenance costs typical of similar equipment were used in the systems analysis to enable comparison on a more representative basis.

Phase III -- Systems Analysis

Cost-Effectiveness Analysis of Multi-Mover and Crawler Tractor. The primary purpose of this analysis is to compare the cost-effectiveness of a multi-functional earthmoving machine (Multi-Mover) with a crawler tractor. The operating rates and costs developed in the course of this analysis were employed as input parameters for a computerized transportation model used to evaluate the economics of servicing several landfill sites in a sparsely populated area.

A total of 473 questionnaires were mailed to sparsely populated counties and small towns and cities in the Pacific Northwest and Northern California to determine the type of equipment presently used in landfill operations. The results of the survey indicate the use of a wide variety of equipment, ranging in size from a small agricultural tractor to 20 yd^3 capacity scrapers. The most frequently used equipment is a medium size (25,000 to 40,000 lb) crawler tractor equipped with either a bulldozer blade or a bucket loader. Several of those responding reported the use of equipment larger than usually recommended for landfills of the size they operate. This is attributable to the fact that many landfills are operated by county and municipal governments that minimize equipment inventory by sharing equipment between landfill operations and road work; road construction and maintenance requires the larger capacity equipment.

Method of Analysis. The first step in the analysis was to develop an operations flow diagram to establish the various operations required in a sanitary landfill and their relationships. The operations were chosen to provide a reasonable balance between the detail required for validity and ease of data collection and manipulation. To facilitate comparisons of productivity under normal landfill conditions, some of the operations were combined into groups, or tasks. A task consists of the operations required to perform a common landfill function, such as excavating a cell. Each task and its component operations are listed in Table 11 in order of their performance.

Certain operations may exist as alternative tasks. For example, in a trench-type operation, after a load of material is excavated from the trench it may be transported to either a stockpile for dumping or to a partially completed cell for spreading to a controlled depth. The flow will depend on the specific requirements and operating policies of the particular site.

Data obtained from test site time and motion studies were used to develop average time coefficients for each task. Table 11 shows the time per unit work for each operation and each task for both the Multi-Mover and the crawler tractor. The Multi-Mover is faster than the crawler tractor in performing every task. The performance parameters were developed from time and motion data collected under controlled conditions.

The Multi-Mover is more than twice as fast as the crawler tractor in spreading waste. This is due to the large blade area of the Multi-Mover compared to the small bucket on the crawler tractor. Had the crawler tractor been equipped with a bulldozer or trash blade the comparison would have been more equal. Both machines tended to catch and tear loose waste that had already been spread. The operator of the crawler tractor could see this happen and correct it by

TABLE 11

LANDFILL TASKS AND OPERATIONS PERFORMANCE PARAMETERS FOR MULTI-MOVER AND CRAWLER TRACTOR

TASKS			OPERATIONS		
	Performance Parameter			Performance Parameter	
Tasks	Multi-Mover	Crawler Tractor	Operation	Multi-Mover	Crawler Tractor
Excavate cell	$t = (0.045\ d + 54)\ \frac{sec}{yd^3}$	$t = (0.38\ d + 39)\ \frac{sec}{yd^3}$	Load earth	3 yd^3 in 90 sec	1-1/4 yd^3 in 30 sec
			Transport to stock pile	$t = 0.081\ d + 5.5$ sec	$t = 0.24\ d + 2$ sec
			Unload	3 yd^3 in 60 sec	1-1/4 yd^3 in 15 sec
			Return to cell	$t = 0.054\ d \times 6.4$ sec	$t = 0.24\ d + 2$ sec
Spread waste	10 sec/yd^3	23.1 sec/yd^3	Spread waste	6.0 yd^3/min	2.6 yd^3/min
Compact waste	8.1 sec/yd^3	14.3 sec/yd^3	Compact waste	7.4 yd^3/min	4.2 yd^3/min
			Travel to stockpile	$t = 0.054\ d + 6.4$ sec	$t = 0.24\ d + 2$ sec
Spread cover from stockpile	$t = 0.06\ d + 44$	$t = 0.38\ d + 39$	Load cover	2-1/4 yd^3 in 42 sec	1-1/4 yd^3 in 20 sec
			Transport to cell	$t = 0.081\ d + 5.5$ sec	$t = 0.24\ d + 2$ sec
			Spread	2-1/4 yd^3 in 45 sec	1-1/4 yd^3 in 25 sec
			Travel to stockpile	$t = 0.054\ d + 6.4$ sec	$t = 0.24\ d + 2$ sec
Spread excavated cover	$t = 0.045\ d + 54$	$t = 0.38\ d + 47$	Load cover	3 yd^3 in 90 sec	1-1/4 yd^3 in 30 sec
			Transport to cell	$t = 0.081\ d + 5.5$ sec	$t = 0.24\ d + 2$ sec
			Travel to excavation	$t = 0.054\ d + 6.4$ sec	$t = 0.24\ d + 2$ sec
Compact cover	$0.115\ \frac{sec}{ft^2}$	0.169 sec/ft^2	Compact cover	3 yd^3 in 60 sec 523 ft^2/min	1-1/4 yd^3 in 25 sec 355 ft^2/min

Note: d = one-way hauling distance in feet.

lifting the bucket to drop the offending object(s). The operator of the Multi-Mover frequently could not see the blade area, and even if he did, the Multi-Mover's box could not be lifted high enough to drop a large object. The crawler tractor was frequently able to produce smoother waste cells, particularly when the waste included bulky objects such as tires. The difficulties caused by the Multi-Mover's maximum blade height were compounded by a tendency for the wheels to sink into soft areas of the cell, effectively lowering the blade and digging up already-compacted waste.

The Multi-Mover was operated by several different people in the course of making the time and motion studies, and no one operated the machine long enough to become really proficient in its operation. On the other hand the operators of the crawler tractors were well experienced in operation of their machines in landfills. Although efforts were made to discount data taken when the Multi-Mover operators were unfamilar with the machine's operation, it is expected that the data are somewhat biased in favor of the crawler tractor.

The task time data which depend on haul distance were handled in the following manner: Observed times were recorded for several different haul distances and then a least-squares linear regression analysis was used to determine the equation of the regression line. This approach was used to simplify later modeling of the tasks for various haul distances and the determination of breakeven points. A typical set of experimental data is presented in Table 12 along with the values calculated with use of the regression line. The percentage differences between the calculated and measured values are also given.

Cost Estimation -- Multi-Mover. Table 13 summarizes the derivation of the hourly operating costs for the Multi-Mover. The selling prices of $45,000 is based on estimates of production costs made in 1967. These costs were modified to reflect the inflation in producers' durable equipment-construction machinery as given by the U.S. Department of Commerce, Bureau of the Census, Survey of Current Business, July 1970. The estimated 1970 manufacturing cost is $30,000. The total cost of promotion, distribution, service under warranty, profit, and related selling costs is estimated at 50% of the total manufacturing cost, bringing the total selling price to $45,000.

The cost of capital was assumed to be 8% annually and the insurance rate was assumed to be 1% of the new value of the machine per year. The salvage value of the machine after 10,000 hr was estimated at 25% of the original selling price.

Operating expenses were estimated by applying the current costs of fuel and lubricating oils in the Richland, Washington area to consumption rates based on equipment manufacturer's estimates for similar-sized equipment. This approach was

TABLE 12

CALCULATED AND MEASURED TRAVEL TIMES FOR LADEN MULTI-MOVER

Distance (ft)	Calculated Time (sec)	Measured Time (sec)	Difference (%)
50	9.6	10.0	4.0
100	13.6	11.6	-14.7
200	21.7	23.0	6.0
500	46.0	47.6	-3.5
1000	86.5	90.0	4.0

TABLE 13

SUMMARY OF MULTI-MOVER HOURLY OPERATING COSTS

10,000 hour useful lifetime over 5 years

	5-Year Total	$/Hr	
Initial cost (excluding sales tax)	$ 45,000		
Interest @ 8% annual rate	10,035		
Insurance	2,250		
Total	$ 57,285		
Less salvage value	11,250		
Net capital cost (owning expense)	$ 46,035		4.60
Fuel @ 4.5 gal/hr and $0.188/gal		0.85	
Tires @ $500 each and 2000 hr life		1.00	
8000-hr major overhaul	1,500	0.15	
Repairs and labor @ 20% of initial cost		0.90	
Lubricants, etc.		0.32	
Total hourly operating expense			3.22
Total hourly owning and operating expense			7.82

chosen in preference to relying on actual operating data since numerous minor problems with various systems were encountered, which resulted in abnormally high consumption of transmission fluid, hydraulic oil and diesel fuel. The present design of the machine does not offer reliability equal to competitive equipment now on the market. Redesign to make reliability and longevity comparable to that of currently available equipment is considered a prerequisite to successful marketing of the machine. This would also result in lubricant and hydraulic fluid use rates similar to currently marketed machinery.

Actual maintenance costs observed during the test program were not considered reasonable estimates of those which could be expected for a production version of the Multi-Mover. The maintenance cost estimate was derived from those suggested by the manufacturers of currently available equipment. Since the estimate is expressed as a percentage of the owning expense, the complexity of the Multi-Mover is reflected in the owning expense and the absolute maintenance cost is proportionately higher than that for the wheeled loaders on which the percentages were based. The overhaul cost and time period were similarly derived.

Tire life was particularly difficult to estimate because of the expected multiple use of the Multi-Mover (i.e., on highways, haul roads, and waste cells). If the Multi-Mover were used to haul maximum loads of cover material moderate distances at highway speeds, tire life would be only a small fraction of that which would be expected if the same time was spent at lower speeds and short hauls on landfill haul roads. (The section of this report entitled "Sensitivity of Cost Estimates to Initial Assumptions" discusses the effect of errors in estimation of any parameter on the total estimate of cost-effectiveness.) An estimate of 2000 hr average tire life was chosen after discussions with several dealers of tires for heavy equipment.

No estimate of taxes was included in the cost estimates because this will of course vary from state to state. If the Multi-Mover is to be used on the public highways it will require some type of vehicle license. The fee and licensing structure will vary from state to state, and for this reason, it is not included in the analysis. State and federal highway taxes, which would have to be paid on the fuel used for highway travel, are not included for the same reason. Fuel taxes are included in the cost of operating the tractor-trailer for transporting the crawler tractor, because those taxes are included in the sales price of the gasoline; however, no other taxes or license fees are included.

Cost Estimation -- Crawler Tractor. Table 14 summarizes the hourly operating costs for a crawler tractor with a front end loader. The initial cost of $24,000 was the estimate

TABLE 14

SUMMARY OF CRAWLER TRACTOR OPERATING COSTS

10,000 hour lifetime over 5 years

	5-Year Total	$/Hr	
Initial cost (excluding sales tax)	$ 24,000		
Interest @ 8% annual rate	5,350		
Insurance	1,200		
Total	$ 30,550		
Less salvage value	7,500		
Net capital cost (owning expense)	$ 23,050		$ 2.30
Fuel @ 4.0 gal/hr and $ 0.188/gal		0.75	
5000-hr major overhaul	7,500	0.75	
Repairs and labor @ 55% of initial cost		1.32	
Lubricants, etc.		0.22	
Total hourly operating expense			3.04
Total hourly owning and operating expense			$ 5.34

obtained from the manufacturer's representative. Interest, insurance, and salvage value were estimated in the same manner as those for the Multi-Mover.

The fuel, lubrication, and hydraulic fluid use rates were obtained from the manufacturer's representative and costs are based on current prices for the Richland, Washington area. These costs will vary with location and supplier. The manufacturer's estimates were used in preference to observed values for two reasons: first, to make the estimating procedure for the crawler tractor and Multi-Mover as similar as possible, and second, because the crawler tractor was in a poor state of repair during the testing, the use rates and maintenance costs encountered were not expected to be typical of those which would be experienced over the entire lifetime of the machine.

The literature received from the manufacturer estimated repairs and maintenance expense at 90% of the owning expense and did not include separate estimates for major overhaul of the machine. Cost of a 5000 hr major overhaul was estimated at $7,500 and the 90% figure was adjusted downward to reflect this change. After this change the repair and maintenance expenses estimate was found to be reasonably consistent with the rates suggested by other manufacturers of crawler tractors.

Sensitivity Analysis. The results of a cost-effectiveness analysis depend on the estimates of cost and productivity.

Since the cost and productivity estimates are based partially on assumptions and engineering estimates rather than entirely on historical data, it is appropriate to investigate the sensitivity of the final estimates to changes in each component.

Tables 15 and 16 show the major components of cost for the Multi-Mover and the crawler tractor, respectively, and for four levels of cost aggregation: Capital Cost, Operating and Maintenance Cost (fuel, lubricants, repairs and maintenance costs), Total Machine Cost (Capital Cost plus Operating and Maintenance Cost) and Total Operating Cost (Total Machine Cost plus operator's wages and benefits). The body of each table shows the effect on the aggregated cost of a 10% change in the component cost. (Negative figures indicate that an increase in a component value results in a decrease in aggragated cost.) For instance, in Table 15, if the hourly cost of fuel is increased by 10% (i.e., from $0.85 to $0.94/hr), the Operating and Maintenance Cost increases by 2.6%, the Total Machine Cost increases by 1.1% and the Total Operating Cost increases by 0.7%. The capital cost is unaffected.

The percentages given in these tables are both linear and additive. A 20% increase in a component cost will affect the aggregated costs twice as much as a 10% increase. The individual effects of simultaneous changes in two or more components may simply be summed to determine their joint effect on an aggregate. For example, the effect on Multi-Mover's Total

TABLE 15

EFFECT OF 10% CHANGE IN COMPONENT COSTS ON AGGREGATED COSTS FOR THE MULTI-MOVER

		Effect in % of a +10% Change in Component Cost Estimate			
Component Cost	Estimated Value	Capital Cost	Operating Maintenance Cost	Total Machine Cost	Total Operating Cost
Purchase price	$ 45,000	9.8	NE	7.3	4.9
Interest 5-yr total	10,035	2.2	NE	1.3	0.9
Insurance 5-yr total	2,250	0.5	NE	0.3	0.2
Salvage value	11,250	-2.4	NE	-1.4	-1.0
Fuel cost/hr	0.85	NE	2.6	1.1	0.7
Tire cost/hr	1.00	NE	3.1	1.3	0.9
Lubricant, etc/hr	0.32	NE	1.0	0.4	0.3
Repairs & maint./hr	0.90	NE	2.8	1.2	0.8
Major overhaul	1,500	NE	0.5	0.2	0.1
Operator's cost/hr	3.75	NE	NE	NE	3.2

N.E. = no effect.

TABLE 16

EFFECT OF A 10% CHANGE IN COMPONENT COSTS ON AGGREGATED COSTS FOR THE CRAWLER TRACTOR

		Effect in % of a 10% Change in Component Cost Estimate			
Component Cost	Estimated Value	Capital Cost	Operating Maintenance Cost	Total Machine Cost	Total Operating Cost
Purchase price	$ 24,000	13.2	N.E.	5.7	3.4
Interest 5-yr total	5,350	2.3	N.E.	1.0	0.6
Insurance 5-yr total	1,200	0.5	N.E.	0.2	0.1
Salvage value	7,500	-3.3	N.E.	-1.4	-0.8
Fuel cost/hr	0.75	N.E.	2.5	1.4	0.8
Lubricants, etc./hr	0.22	N.E.	0.7	0.4	0.2
Repairs & maint./hr	1.32	N.E.	4.3	2.5	1.4
Major overhaul	7,500	N.E.	2.5	1.4	0.8
Operator's cost/hr	3.75	N.E.	N.E.	N.E.	4.1

N.E. = No effect.

Machine Cost of a 15% increase in insurance cost and a 7% decrease in tire costs would be determined as follows:

$$\frac{15}{10} \times 0.3 + \frac{-7}{10} \times 1.3 = -0.46$$

a 46/100 of one percent decrease in Total Machine Cost.

The Multi-Mover and the crawler tractor are more highly sensitive to the purchase price than to any other single component cost, with the Multi-Mover being slightly more sensitive. This results because the operating and maintenance costs of the two machines are nearly equal (at \$3.22/hr and \$3.04/hr for the Multi-Mover and the crawler tractor, respectively) while the Multi-Mover's purchase price is nearly twice that of the crawler tractor. This affects the other capital-related costs such as interest and insurance. The sensitivity of the Multi-Mover's costs to the purchase price is unfortunate because the purchase price is the most difficult of the costs to estimate. Although the manufacturing cost of the machine can be estimated with a reasonable degree of confidence, the costs of promoting and distributing the machine are more difficult to estimate. These costs depend on the firm marketing the machine, whether the marketing is done through an established manufacturer of heavy machinery, what financial backing is available to the enterprise, and the reputation of the marketing organization.

Tire cost per hour was another difficult factor to assess with any degree of certainty. Experience with the prototype machine is not particularly enlightening for several reasons: first, the size of the existing planetary hubs fitted to the machine made it impossible to use tires rated for the maximum gross weight of the machine; second, the machine has not been operated a sufficient number of hours to make a reasonable assessment of the average tire life; third, the actual life of the tires will depend greatly on the particular conditions under which the Multi-Mover is operated. For example, any appreciable amount of hauling cover material at highway speeds will shorten tire life. Fortunately, the total operating cost is not overly sensitive to the tire cost and would increase less than 9% if the per hour cost of tires were doubled.

The crawler tractor costs were more sensitive to repairs and maintenance, major overhaul, and operator's costs. Repairs, maintenance and overhauls tend to be more expensive for track-type vehicles than for wheeled vehicles. Crawler tractors generally require at least one major overhaul of the complex and expensive undercarriage in their 10,000 hr lifetime, in addition to the general power plant overhaul required by both wheeled and tracked machines. The undercarriage is also the prime reason for higher cost of routine repairs and maintenance for the crawler tractors.

The cost-effectiveness evaluation is based on estimates of costs and productivity (unit of work per unit of time). There are certain basic tasks which must be performed in the operation of any landfill. As an example, one task in a trench-type landfill is digging the trench. One likely series of operations for a crawler tractor would be; (1) fill bucket with earth, (2) drive tractor to stockpile, (3) dump earth on stockpile (4) drive back to cell, and (5) repeat steps 1 through 4 as required to obtain the size trench desired. Other levels of breakdown are also possible. It would of course be possible to break step 2 down into steps such as shifting gears, manipulating the steering clutches and so on, but this can lead to a complex procedure for estimating the time required to perform the major tasks. Therefore, the level of major breakdown was selected to give accurate results without requiring unreasonable effort in either data collection or analysis. Greater detail in defining the operations would mean that hypothetical cases for comparison would have to be specified in correspondingly greater detail. Since the operations will not be carried out in exactly the same way each time, it is appropriate to examine the effect of each operation in the tasks on which the cost-effectiveness comparisons will be primarily based. Table 11 showed the operations for which performance data was obtained and the grouping of these operations into major tasks. Tables 17 and 18 are analogous to Tables 15 and 16 and show the effects that a change in the estimation of one operation's performance parameter will have on the major tasks. As an example, a 10% increase in the Multi-Mover's cover spreading time will result in a 3.2% increase in the time required to spread and compact cover when the cover is excavated as needed. The factors given in Tables 17 and 18 may be used to estimate the effects of specific operating conditions; for example, from Table 18, if the site under consideration has a soil which has a high percentage of clay and we feel that this will cause a 25% increase in loading times, we can determine the percentage increase in time required to excavate a trench as follows, using Table 18:

$$(4.1 \times 25/10) = 10.3.$$

Since the times required to perform several of the operations are functions of the haul distance, it is important to assess the effect of this distance on the various sensitivities. The effects of haul distance on the sensitivities of the tasks "Excavate Trench" and "Spread Cover from Stockpile and Compact" to a 10% change in operation times are shown in Tables 19 and 20. Increasing the haul distance decreases the sensitivity to changes in loading, spreading, and dumping times for both machines, but the effect is more apparent for the crawler tractor. As that portion of the time required for hauling

TABLE 17

EFFECT OF A 10% CHANGE IN OPERATION TIMES ON MAJOR TASK TIMES FOR THE MULTI-MOVER

	Effect in % of a 10% Change in Operation Time			
Operation	Excavate Trench	Spread and Compact Waste	Spread and Compact Cover From Stockpile	Spread and Compact Cover From Excavation
Loading time (scraping)	5.3	N.E.	N.E.	4.8
Loading time (vertical bank)	N.E.	N.E.	3.5	N.E.
Optimum load (scraping)	-1.0	N.E.	N.E.	-0.9
Optimum load (vertical bank)	N.E.	N.E.	-1.4	N.E.
Travel time (empty)	0.5	N.E.	0.8	0.5
Travel time (loaded)	0.6	N.E.	0.8	0.5
Cover spreading time	N.E.	N.E.	3.8	3.2
Cover dumping time	3.6	N.E.	N.E.	N.E.
Waste spreading time	N.E.	5.5	N.E.	N.E.
Waste compacting time	N.E.	4.5	N.E.	N.E.
Cover compacting time	N.E.	N.E.	1.2	1.0

N.E. = No effect.

TABLE 18

EFFECT OF A 10% CHANGE IN OPERATION TIMES ON MAJOR TASK TIMES FOR THE CRAWLER TRACTOR

Operation	Effect in % of a 10% Change in Operation Time Excavate Trench	Spread and Compact Waste	Spread and Compact Cover From Stockpile	Spread and Compact Cover From Excavation
Loading time (scraping)	4.1	N.E.	N.E.	3.2
Loading time (vertical bank)	N.E.	N.E.	2.4	N.E.
Optimum load (scraping)	-6.7	N.E.	N.E.	-5.2
Optimum load (vertical bank)	N.E.	N.E.	-3.0	N.E.
Travel time (empty)	1.9	N.E.	1.7	1.5
Travel time (loaded)	1.9	N.E.	1.7	1.5
Cover spreading time	N.E.	N.E.	2.9	2.6
Cover dumping time	2.0	N.E.	N.E.	N.E.
Waste spreading time	N.E.	6.2	N.E.	N.E.
Waste compacting time	N.E.	3.8	N.E.	N.E.
Cover compacting time	N.E.	N.E.	1.4	N.E.

N.E. = No effect.

TABLE 19

SENSITIVITY OF "EXCAVATE TRENCH" TASK TO A 10% CHANGE IN OPERATION TIMES FOR SEVERAL HAUL DISTANCES

Multi-Mover

Parameter Affected	% of Change for Haul Distances 50 ft	100 ft	500 ft	1000 ft
Loading time	5.34	5.13	3.92	3.03
Optimum load	-1.01	-1.32	-3.15	-4.50
Travel time	1.11	1.44	3.47	4.96
Spread & dump time	3.56	3.42	2.62	2.02

Crawler Tractor

Parameter Affected	% of Change for Haul Distances 50 ft	100 ft	500 ft	1000 ft
Loading time	4.11	3.09	1.04	0.57
Optimum load	-3.49	-4.87	-7.68	-8.32
Travel time	3.82	5.36	8.44	9.16
Spread and dump time	2.05	1.55	0.52	0.28

TABLE 20

SENSITIVITY OF "SPREAD COVER FROM STOCKPILE AND COMPACT" TASK TO A 10% CHANGE IN OPERATION TIMES FOR SEVERAL HAUL DISTANCES

Multi-Mover

Parameter Affected	% of Change for Haul Distances			
	50 ft	100 ft	500 ft	1000 ft
Loading time	3.51	3.32	2.33	1.69
Optimum load	-1.42	-1.83	-4.00	-5.39
Travel time	1.57	2.02	4.40	5.93
Spread and dump times	3.76	3.56	2.50	1.82
Compact cover time	1.17	1.10	0.77	0.56

Crawler Tractor

Parameter Affected	% of Change for Haul Distances			
	50 ft	100 ft	500 ft	1000 ft
Loading time	2.37	1.84	0.67	0.37
Optimum load	-3.02	-4.36	-7.38	-8.14
Travel time	3.32	4.78	8.12	8.96
Spread and dump times	2.96	2.31	0.83	0.46
Compact cover time	1.35	1.05	0.38	0.21

increases, increasing the speed at which the machine is capable of loading and emptying becomes less and less effective in reducing total time. This is emphasized for the crawler tractor since its speed is slower and its load and unload times are less significant. As expected, sensitivity to changes in travel time and optimum load increase with longer haul distances and this effect is more pronounced for Multi-Mover than for the crawler tractor.

Comparison of Cost-Effectiveness. The estimates of the costs associated with the operation of each machine and the times required to perform typical landfill operations were combined into one set of cost-effectiveness parameters. There are several different cost parameters as well as different performance parameters which may provide relevant comparisons between the two machines. The most important of these is the total cost/unit work performed. Others which might be of interest include the fixed expense/unit work or fixed expense/yr, operating cost/unit work and labor cost/unit work.

The Multi-Mover's cost/unit work is lower than that of the crawler tractor for the waste spreading, waste compacting and cover compacting operations (Table 21). The cost/unit work for the other operations depends on the distances involved. (Figures 11, 12, and 13 compare the cost/unit work of the Multi-Mover and crawler tractor in excavating trenches,

TABLE 21

COST/UNIT WORK FOR MULTI-MOVER AND CRAWLER TRACTOR

Task	Multi-Mover	Crawler Tractor
Excavate trench	(0.144 d(1) + 173) $\frac{\text{dollars}}{1000\ \text{yd}^3\ \text{excavated}}$	$(0.96\ d + 98)\ \frac{\text{dollars}}{1000\ \text{yd}^3\ \text{excavated}}$
Spread waste	\$32.10/1000 yd^3 loose(2)	\$58.30/1000 yd^3 loose
Compact waste	\$26.00/1000 yd^3 loose/pass(3)	\$36.10/1000 yd^3 loose/pass
Spread cover from stockpile	$(0.192\ d + 141)\ \frac{\text{dollars}}{1000\ \text{yd}^3}$	$(0.96\ d + 98)\ \frac{\text{dollars}}{1000\ \text{yd}^3}$
Spread cover from excavation	$(0.144\ d + 173)\ \frac{\text{dollars}}{1000\ \text{yd}^3}$	$(0.96\ d + 119)\ \frac{\text{dollars}}{1000\ \text{yd}^3}$
Compact cover	\$0.37/1000 ft^2/pass(3)	\$0.43/1000 ft^2/pass
Travel between sites	\$0.83/mile	\$0.52/mile + \$3.64

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(1) d = one-way haul distance from trench or cell to stockpile or other cell.

(2) Waste spreading and compaction figures are based on as-delivered volumes of waste. This was delivered primarily by compactor-type collection vehicles, and yardages are based on as-delivered volume and not on volumes loaded into the trucks.

(3) A pass is defined as a series of trips across the area to be compacted so that the entire area receives one tire or track mark.

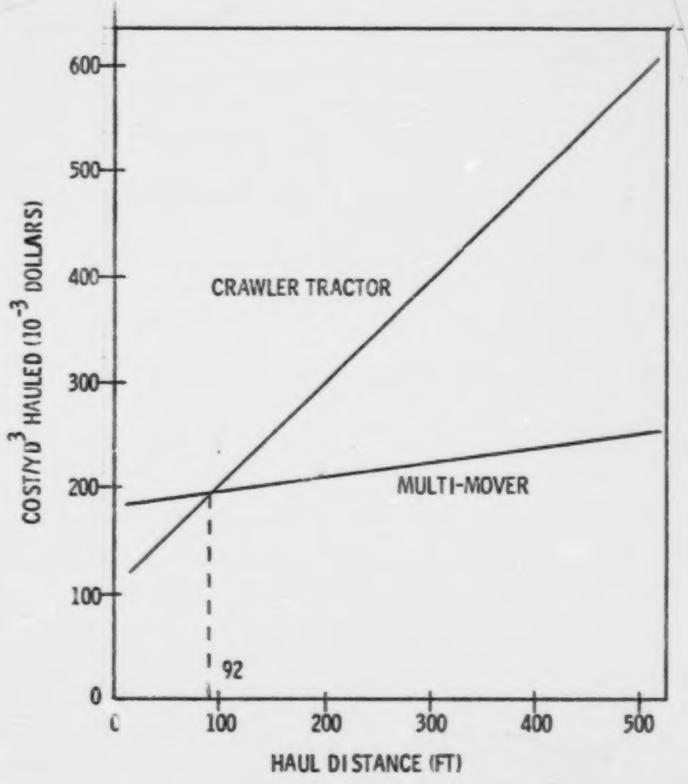

Figure 11. Cost/yd^3 Excavated vs Haul Distance to Stockpile

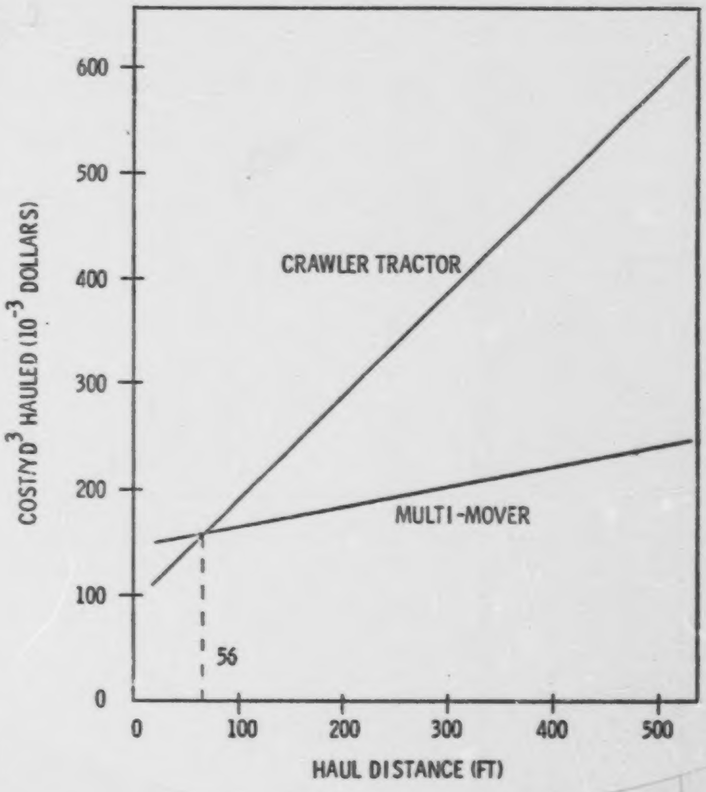

Figure 12. Cost/yd^3 Spread from Stockpile vs Haul Distance from Stockpile to Cell

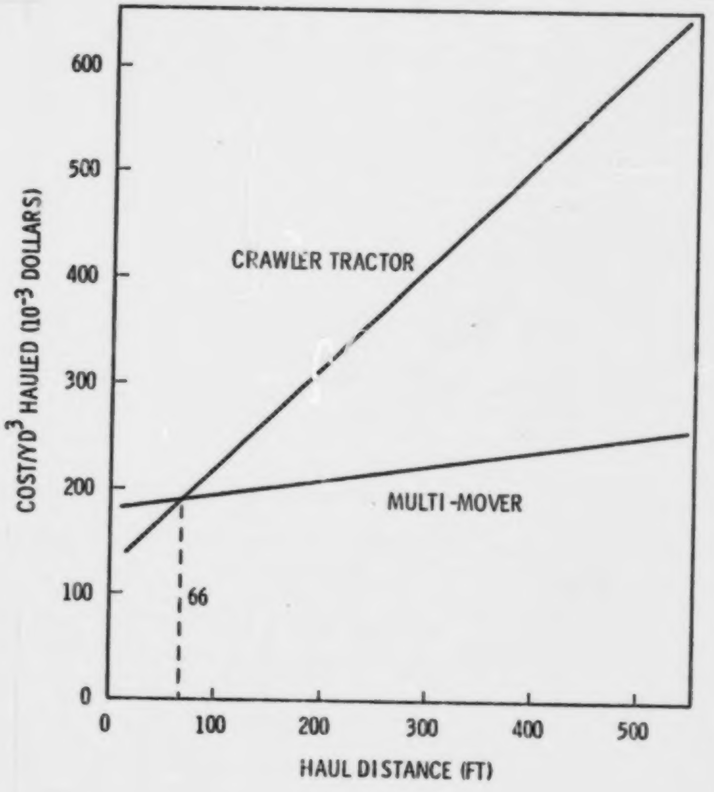

Figure 13. Cost/yd^3 Excavated Cover Spread vs Haul Distance to Cell

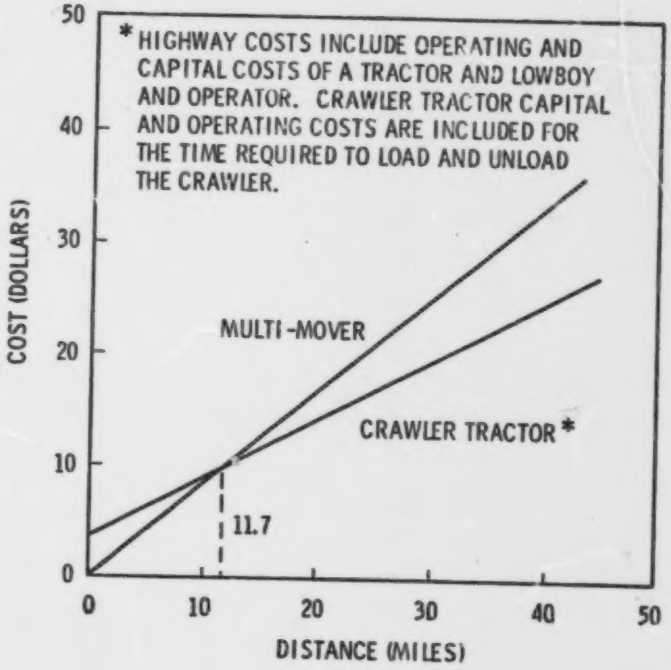

Figure 14. Transporting Cost vs Distance for Multi-Mover and Crawler Tractor

spreading cover from a stockpile, and spreading cover from an excavation, respectively.) The breakeven points (i.e., the distances at which the cost of doing the work with the Multi-Mover is equal to that of doing the work with the crawler tractor) vary from 56 ft for spreading stockpiled cover material to 92 ft for excavating trenches. The Multi-Mover's cost/mile of highway travel is lower for distances shorter than 11.7 miles (Figure 14). The crawler tractor is more economical at short haul distances because of its faster loading and dumping times. Multi-Mover's greater speed and payload make it the more economical of the two machines at longer haul distances. These breakeven distances are all within the range that would be encountered in many landfill operations. If several landfills were being considered for service by the same machine, the crawler might be slightly more economical at some sites and the Multi-Mover at others. In general, it is not possible to say that either machine should prove superior consistently in normal landfill operations for these tasks; the economics would depend on the circumstances at the particular landfill.

Systems of landfills for sparsely populated areas are usually planned with a goal of providing a disposal site within 8 to 15 miles of each resident in the area. In Canyon County, for example, the goal of a recent plan was a maximum distance of 12 miles. In general, the average distance between sites will be something less than thwice the maximum distance any resident is expected to travel. This will vary substantially with the topography and road network of a given area. Whether the Multi-Mover or crawler tractor is the more economical will depend on the specific situation.

The performance parameters used in this study have some limitations. The times required for each of the operations were obtained under controlled test conditions and do not exactly reflect normal landfill operations. In actual practice the operator cannot possibly operate at maximum efficiency and concentration at all times. During the data collection, the operator was instructed to work at his normal pace but it is not realistic to assume he could maintain this pace all day. There should be consideration in normal operation. Rest stops and the like would take their toll, and therefore, the parameters we have used certainly overestimate the average productivity of both machines. In addition, certain simplifying assumptions were required in developing the models on which the comparisons are based. As an example, the time required to excavate a trench will depend not only on the volume to be excavated and the distance to be hauled, but on other factors such as the type of ground, the depth of the trench, the amount of turning and maneuvering required on each trip, the weather, and operator productivity. It was not feasible to evaluate all these factors and still retain a sufficient degree of flexibility and generality. Therefore, the evaluation was made with the help of simplified tasks. Since all of the pertinent factors could not be taken into consideration, every attempt was made to make the evaluations of the two machines comparable.

An additional factor could account for some of the variables which could not be included explicitly. If we assume the performance parameters used reflect 100% efficiency then we can develop efficiency factors for each piece of equipment to account for such factors as maneuverability, operator fatigue, operating ease, etc. These factors could be applied for each individual operation, each major task, or the entire landfill operation. The efficiency factors could be evaluated simply by observing the operation of each machine over a long period of time and then comparing the actual times required for the tasks and operations with the times predicted by the 100% efficiency parameters. Unfortunatley this type of observation was not within the scope of this study. The efficiency of the two machines is unlikely to be exactly the same, but quantitative data is not available on which to base any other conclusions. This costeffectiveness analysis implicity assumes that the efficiencies are not significantly different.

Transportation Model. A way of reducing the cost of maintaining disposal sites in sparsely populated areas would be to service several remote, small waste disposal sites with multi-functional equipment of highway mobility, such as the Multi-Mover.

A computer-based model has been developed to study the economics of such an operation. The model compares two types of equipment, which must be described by the model user in terms of capabilities and operating costs. In this context, an equipment type may describe a single machine, or a group of machines working together.

In computer runs made for this study, the Multi-Mover was compared with a single crawler tractor equipped with a 1-1/4 yd^3 bucket in the operation of several sanitary landfill sites in Canyon County, Idaho. In these computer runs, the Multi-Mover has exhibited a definite economic advantage.

Model Description. The model simulates the operation of a number of waste disposal sites with various types of equipment. Any two types of equipment may be modeled, but capability and cost data must be specified by the model user. The model consists of a set of linear constraints representing the services required at each disposal site and the capacity limitations on each type of equipment. The model was designed to compare the effectiveness of the Multi-Mover with the effectiveness of conventional types of equipment in landfill operations and to determine optimum use of the equipment. The objective function for the optimization is a linear equation representing the cost of owning and operating the equipment.

The principle variables in the model formulation represent a trip made by a particular type of machine. A trip represents traveling to a combination of up to three sites and performing the tasks required in a typical landfill operation. These tasks are:

1. Excavating before fill (when needed).
2. Spreading waste.
3. Compacting waste.
4. Spreading cover (from stockpile or excavation).
5. Compacting cover.

An arbitrary limit of three sites per trip was chosen because the work at three sites normally requires a substantial time (two to three days or more) and the equipment would require maintenance or be required back to start another cycle before more than three sites were serviced. Using more than three sites greatly increases the number of travel combinations, resulting in excessively complicated programming and longer solution times. Furthermore, the additional savings in travel time becomes negligible compared to the overall costs of the trip, thus more sites per trip would not appreciably affect the solution. All combinations of one, two, or three sites are possibilities examined in the model.

In addition to the trip variables, there are variables representing slack in the constraints. The slack in the service requirement constraints represents requirements that cannot be satisfied with available equipment. These unsatisfied services are assumed to be performed by rental equipment. The model assumes that an unlimited amount of the second specified equipment type is available for rent at a price specified by the model user. The slack in the capacity constraints represents unused capacity. The capacity slacks are allowed to go negative by a limited percentage of total capacity with a cost penalty, thus representing driver and equipment overtime costs. The model is based on a 40 hr work week. The amount of overtime allowed and the overtime cost must be specified by the user.

There are two types of constraints in this model, first, the services required constraints, and second, the equipment capacity constraints. The services required constraints stipulate the number of times each site should be serviced within the defined model period. There is one of these constraints for each disposal site. They may be written, for each site k,

$$\sum_{i=1}^{N} \sum_{j=1}^{M} \delta_{jk} t_{ij} + r_k = S_k, \qquad (1)$$

where

N = number of types of equipment

M = number of trips (all combinations of 1, 2, and 3 sites)

t_{ij} = variable representing type i servicing the jth combination of sites

δ_{jk} = 1 when site k is included in the jth combination of sites; 0 otherwise

r_k = the variables representing the number of times site k is serviced by rental equipment

S_k = the number of times site k will be serviced in the model period

The equipment capacity constraints limit the hours each type of equipment is used. There is one capacity constraint for each type of equipment. It may be written for each type i

$$\sum_{j=1}^{M} h_{ij}\, t_{ij} = B_i, \qquad (2)$$

where

M and t_{ij} are as described in Equation (1)

h_{ij} = the total hours for a type i machine to travel and service the jth combination of sites

B_i = the total capacity (hours) of operating time expected for type i

The objective function represents the total equipment operating cost and rental costs incurred to perform the services required at all the disposal sites. It may be written

$$\sum_{i=1}^{N} \sum_{j=1}^{M} c_{ij} t_{ij} + \sum_{k=1}^{L} d_k r_k = Z, \qquad (3)$$

where

N, M, t_{ij}, r_k are as described in Equation (1)

c_{ij} = the total operating cost for type i to travel and service the sites in combination j

d_k = the cost to have rental equipment service site k

Z = the objective function value

The coefficients h_{ij}, B_i, c_{ij}, and d_k are calculated by the computer program and are discussed under Program Description.

The goal of the optimization is then to find the solution to the constraints defined above, which results in the lowest value for the objective function. Linear programming, a well developed optimization technique, would solve this problem very efficiently. However, the results would not necessarily be integer values, and a partial trip is not meaningful. Various algorithms have been developed to find the optimum integer solutions, but in general they are time consuming and costly to solve with a computer. Therefore, a modified linear programming solution algorithm was developed.

"Pivoting" is a term applied in linear algebra to the process of manipulating a set of simultaneous linear equations so that a given variable will have a coefficient of one in only one equation and be eliminated (coefficient of zero) in all of the other equations. This process is performed using only elementary transformations resulting in an equivalent (same solutions) set of linear equations. In effect, the process of pivoting brings the variable into the basic solution and removes another variable previously in the solution. Each pivot performs one iteration in the linear programming algorithm.

The modified algorithm has the following changes from the standard linear programming algorithm: (1) pivots are made only on coefficients equal to one, causing the solution to remain integer; (2) pivots are made only on the service requirement constraints, and none are made on the equipment capacity constraints; and (3) the equipment capacity constraints are used to determine if there is enough capacity to allow the selected pivot. These limitations could prevent some beneficial pivots on the capacity constraints. However, after all acceptable pivots on the requirement constraints have been made, one additional "partial pivot" is allowed on each equipment capacity constraint. The "partial pivot" refers to letting the variable into the solution with value equal to the largest integer that is no larger than its value would be if a normal pivot were made. For instance, if the value of a variable would be 4.7 after pivoting on a capacity constraint, then the value 4.0 is assigned to the variable.

This technique does not insure the optimal integer solution; however, it is a near optimal integer solution and requires a very small amount of computer time for solution. In all cases optimized in the study, whenever adequate Multi-Mover capacity was available, the integer solution was optimal.

Currently, the model assumes a fixed number of each type of equipment is available. Capital cost for financing the purchase is prorated on an hourly usage basis and included in the hourly operating cost. Since the solution algorithm is very efficient, this model could be incorporated into a dynamic programming model over an extended period of time. By inputting projected waste disposal requirements, and using present value techniques, the optimum equipment purchasing schedule for an extended period could be analyzed.

Program Description. A Fortran program was written for the Univac 1108 to generate the model and perform the optimization. This program may be converted for use on other computers with only a minimal amount of conversion. The program is flexible enough to simulate any type of equipment with known or estimated capabilities servicing any reasonable combination of sites. Various parameters describing the capabilities of the equipment and the disposal site configurations must be provided by the user.

The general flow of the program is as follows:

1. Input all parameters.
2. List model and equipment parameters.
3. For each site, list site parameters and calculate and list the time required for each type of equipment to service a site.

4. Generate all combinations of trip variables, calculating time and cost for each trip.
5. Generate the slack variables for each constraint.
6. Generate the right hand side for each constraint.
7. Assume the starting solution is the slacks (rental and capacity slacks) and make the necessary pivots.
8. Optimize.
9. Report the solution.
10. Input parameters for the next case. Only those values which are changed need to be specified. All other parameters will retain the same value.
11. Proceed to Step 2 above. If no more cases exist, terminate.

The input parameters may be divided into three general categories; these are parameters describing assumptions concerning the overall model (Table 22), the parameters describing the capabilities of the equipment (Table 23), and the parameters describing the operation of each site (Table 24). The parameters are read using the Namelist feature of Fortran.(2)

Using the input parameters, the average time to service a site is a straightforward calculation. The total time to service a site is the sum of the following five items divided by the efficiency factor:

TABLE 22

TRANSPORTATION MODEL AND MODEL PRINT CONTROL PARAMETERS

Designator	Description
Model Parameters	
TM	Model period in weeks
DIST(I,J)	Distance between site (I-1) and site (J-1). If the index is 1, it represents the base location for the equipment. The base location should be the shop or storage area or the most active disposal site.
NSITE	The number of waste disposal sites.
OVC	Additional cost for overtime pay ($/hr).
OVF	Fraction of overtime allowed, based on a 40 hr week.
MAXSPT	Maximum sites per trip. The limit is three. If no value is specified three is assigned.
RENT	The rental price ($/hr) for the second type equipment.
NAMCAS	60-character case title.

Designator	Description
Model Print Control Parameters	
LMP	Model parameters will be listed only if a non-zero value is specified.
LEP	Equipment parameters will be listed only if a non-zero value is specified.
LSP	Site parameters will be listed only if a non-zero value is specified.
LSW	Work calculations for each site will be listed only if a non-zero value is specified.

TABLE 23

EQUIPMENT PARAMETERS

Designator	Description
NAMTYP	12-character equipment name.
FOP	Fraction of time equipment is operable.
COP	Operating cost ($/hr).
CDR	Driver cost ($/hr).
CTR	Travel cost ($/hr).
EFF	Efficiency factor. The operating capabilities are determined for a short test and are not realistic for extended operation. This efficiency factor compensates therefore.
TSW	Time to spread waste (sec/yd^3).
TCW	Time to compact waste (sec/yd^3).

Designator	Description
TSCS	Two parameters representing time/unit volume to spread cover from stockpile as a linear function of the haul distance. If d is the distance between stockpile and fill area, the time/unit volume of cover is equal to the second parameter plus the product of d and the first parameter.
TSCE	Two values (similar to TSCS above) representing the time to excavate and spread cover (sec/yd^3).
TE	Two values (similar to TSCS above) representing time to excavate and stockpile cover (sec/yd^3).
TCC	Time to compact cover (sec/ft^2).
RC	Waste compaction ratio.
TRSP(I,1)	Time to prepare equipment for road travel, and then after traveling to next site, to prepare for work such as on-load and off-load lowboy (hr).
TRSP(I,2)	Road travel speed (miles/hr).
NEQ	Number of machines available.

Note: All equipment parameters are dimensioned and all values must be specified for each type of equipment.

TABLE 24

SITE PARAMETERS

Designator	Description
FE	Fraction of fill volume that must be excavated prior to filling.
FCE	Fraction of cover spread directly as excavated. (1-FCE) then is the fraction of cover spread from the stockpile.
DSC	Average distance from stockpile to fill area (ft).
DES	Average distance from excavation to stockpile (ft).
DEC	Average distance from excavation to fill area (ft).
HL	Depth of compacted waste lift (ft).
HC	Spread depth of cover (ft).
W	Trucked waste volume (yd^3/wk).
NS	Frequency of service (services/model period).
NCC	Number of compaction passes.

Note: All site parameters are dimensioned, and therefore, must be specified for each disposal site.

1. Time to spread waste.
2. Time to compact waste.
3. Time to spread cover from stockpile or excavation. or both.
4. Time to compact cover.
5. Additional excavation when the amount of pre-fill excavation exceeds the amount of excavation used immediately for cover material.

The model coefficients h_{ij} and c_{ij}, discussed previously, represent the hours and cost, respectively, for equipment type i to service the sites in combination j. The hours term is calculated as the sum of the time to service the individual sites plus the time to travel from the base to each of the sites and finally back to the base. The travel time includes the time to prepare for road travel plus the time on the road. The optimum sequence of sites visited is determined by the program and used in the time calculation. The cost term is the sum of travel cost and site servicing cost. The travel cost is the product of travel time and travel cost hourly rate. The service cost is the product of the service time and the sum of the hourly operating rate and driver's salary.

The model coefficient d_k represents the rental cost to service site k. It is the product of rental rate ($/hr) and the time for the second equipment type to service site k. Travel cost is not included since the location of rental equipment is not known. Travel charges should be included in the rental rate.

The model coefficient B_i represents the total capacity (hr) for equipment type i. It is the product of model period in weeks, 40 hr/wk, number of type i equipment available, and estimated fraction of operating time.

Output from this program consists of three general categories: input parameters, calculations made during model generation, and the final solution. The input parameters are grouped as model parameters, equipment parameters, and site parameters. Each group listing is optional and is printed only when parameters LMP, LEP, and LSP, respectively, are set nonzero by the user.

Listing of the calculations made during model generation is also optional and is triggered by parameter LSW. This output includes a breakdown of time required to perform the various landfill tasks in servicing a site with each type of equipment. In addition, the cost of site work and travel is listed for each trip by each type of equipment. The trips are coded as TI-JKL, where T represents trip; I is a single digit representing equipment type; and J, K, and L are single digits representing the sites visited and the travel sequence.

The final solution output includes the objective function value; the amount and percentage of unused capacity for each type of equipment; and a detailed list of trips, hours of capacity used, and cost of each type equipment for each site. The total travel time and cost is allocated to each site based on a weighting factor determined by the distance between the site and the base location.

Modeling Canyon County, Idaho. Canyon County, Idaho is a sparsely populated county with several widely dispersed waste disposal sites. The selection of parameter values was made to simulate the operation of the disposal sites according to Idaho regulations,(3) specifically with respect to frequency of servicing the sites. These regulations are as follows:

> Sanitary landfills should be covered daily. Community modified landfills should be covered twice per year per 100 people, at least 50 times per year, and twice per week between May 15 and September 15. Community improved dumps should be serviced once per year per 100 people, at least four times per year. *

Because of the twice per week requirement in summer for community modified landfills, a one year operation was divided into two model time periods.

Winter -- September 15 to May 15 -- 35 weeks

Summer -- May 15 to September 15 -- 17 weeks

There are five disposal sites modeled in Canyon County. Table 25 lists the data describing service frequency. Table 26 contains other data describing the site operation. Table 27 lists the distance between sites obtained from a County Atlas Co. map. Lake Lowell was assumed to be the equipment base location.

Two types of equipment were modeled, the Multi-Mover and a crawler tractor with a 1-1/4 yd^3 bucket. Table 28 lists the capabilities of each type of equipment. The hourly operating cost is detailed in Tables 13 and 14 for the two equipment

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* Solid waste disposal operations other than sanitary landfills are not considered acceptable by EPA.

TABLE 25

CANYON COUNTY, IDAHO, WASTE DISPOSAL SITES -- SERVICE FREQUENCY

Site	Type *	Population[1]	Waste Input (yd^3/wk)	Yearly Services	Summer Services	Winter Services
Lake Lowell	Sanitary Landfill	49,573	3,619	(52)(5)=260	(17)(5)=85	(35)(5)=175
Middleton	Modified Sanitary Landfill	3,285	304	65	34	31
Central Cove	Modified Sanitary Landfill	4,137	387	82	34	48
Parma	Modified Sanitary Landfill	4,276	396	85	34	51
Melba	Community Improved Dump	885	82	9	5	4

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[1] Population: Recommended Solid Waste Disposal Plan for Canyon County, Idaho. Idaho State Department of Health, June 1969.

* See EPA Comment on page 117.

TABLE 26

CANYON COUNTY, IDAHO, WASTE DISPOSAL SITES -- GENERAL PROGRAM DATA*

Designator	Description	Lake Lowell	Middle-ton	Central Cove	Parma	Melba
FE	Fraction of pre-fill excavation	0	0.5	0	0	0
FCE	Fraction of cover directly from excavation	1.0	1.0	1.0	1.0	1.0
DSC	Average distance from stockpile to fill (ft)		150			
DES	Average distance from excavation to stockpile (ft)		50			
DEC	Average distance from excavation to fill (ft)	300	100	50	30	250
HL	Compacted waste lift depth (ft)	6	6	6	6	4
HC	Spread cover depth (ft)	0.5	0.5	0.5	0.5	0.5
NCC	Number of compaction passes	2	2	2	2	2

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*From R. P. O'Hara, Nampa, Idaho.

TABLE 27

CANYON COUNTY, IDAHO WASTE DISPOSAL SITES -- INTERSITE ROAD DISTANCES*

Site	Base (Mi)	Lake Lowell (Mi)	Middle-ton (Mi)	Central Cove (Mi)	Parma (Mi)	Melba (Mi)
Base	0	0	20	13	34	20
Lake Lowell	0	0	20	13	34	20
Middleton	20	20	0	22	19	40
Central Cove	13	13	22	0	21	33
Parma	34	34	19	21	0	54
Melba	20	20	40	33	54	0

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*From County Atlas Co. map of Canyon County, Idaho.

TABLE 28

EQUIPMENT PARAMETERS

Designator	Description	Multi-Mover	Crawler Tractor
FOP	fraction of uptime	0.9	0.9
TSW	time to spread waste (sec/yd^3)	10.0	23.1
TCW	time to compact waste (sec/yd^3)	8.1	14.3
TSCS	time to spread cover from stockpile (sec/yd^3)	0.06 d + 44	0.38 d + 39
TSCS	time to spread cover from excavation (sec/yd^3)	0.045 d + 54	0.38 d + 47
TE	time to excavate and stockpile (sec/yd^3)	0.045 d + 54	0.38 d + 39
TCC	time to compact cover (sec/ft^2)	0.115	0.169
RC	compaction ratio	4.0	3.0
EFF	efficiency factor	0.5	0.5
CDR	driver cost ($/hr)	3.75	3.75
COP	operating cost ($/hr)	7.82	5.34
CTR	transportation cost	11.57	12.33
TRSP	load-unload time (hr)	0	0.4
TRSP	road speed (MPH)	14	19

types. The transportation cost for the crawler tractor was based on a fixed owning cost of \$0.202/mile, and a variable operating cost of \$0.124/mile, or a total of \$0.326/mile. With an average distance between sites of 26.9 miles, the travel cost in dollars per hour may be derived as:

$$\frac{\text{mileage cost + cost for two drivers}}{\text{time}} =$$

$$\frac{(26.9)(.326) + 2(3.75)(\frac{26.9}{19} + .4)}{\frac{26.9}{19} + .4} = \$12.33$$

Other parameters include operator wages at \$3.75/hr, with a 20% overtime provision paid at straight rate. An overtime penalty factor is used to keep the model from working one machine and driver overtime and having the other idle. The overtime penalty is later removed from the objective function value and therefore, does not distort the answer. The rental price of the crawler tractor is \$20/hr.

Under the conditions assumed in modeling Canyon County, the Multi-Mover exhibits definite economic advantages over the crawler tractor for operation of remote disposal sites. Table 29 exhibits about a two to one capability advantage for the Multi-Mover in the time required to service a site. Since the hourly operating cost for the Multi-Mover is only about 25% higher, it will obviously be the choice in any optimization model. Several cases were run for this study,

TABLE 29

SUMMARY OF CALCULATED TIME TO SERVICE INDIVIDUAL SITES PER VISIT

	Winter			Summer		
Site	Waste (yd^3)	Multi-Mover (hrs)	Crawler Tractor (hrs)	Waste (yd^3)	Multi-Mover (hrs)	Crawler Tractor (hrs)
Lake Lowell	724	7.9	17.0	724	7.9	17.0
Middleton	343	4.9	9.2	152	2.1	4.1
Central Cove	282	3.1	6.2	193	2.1	4.3
Parma	272	2.9	6.0	198	2.1	4.3
Melba	718	8.2	17.6	279	3.2	6.8

changing the equipment availability in each case. The results are summarized in Tables 30 and 31. The final results show that any of the three following equipment combinations would be sufficient to service the sites as modeled:

1. Two Multi-Movers with a total yearly operating cost of $37,512.
2. One Multi-Mover and two crawler tractors with a total yearly operating cost of $48,548.
3. Three crawler tractors with a total yearly operating cost of $59,108.

There are three apparent peculiarities in the solutions. First, in Table 29, rows 2, 3, and 4 show the same hourly usage for the Multi-Mover, but a slightly different cost. This is caused by the program rounding the time to the nearest hour after the total cost has been determined. The total hourly usage in the various lines are the summation of different trip selections that have the same total hours after rounding. Second, a $10/hr cost for overtime has been included to keep the model from working one type equipment overtime while the other type is working only at partial capacity. However, this penalty was insufficient, as indicated by row 4, because Multi-Mover worked at over 100% capacity and the crawler tractor worked at less than 100% capacity. The $10 penalty should be almost sufficient in view of the capability and cost estimates. Third, one case (row 4, Table 31) selected service by rental equipment at $20/hr while the crawler tractor,

TABLE 30

SUMMARY OF RESULTS - WINTER PERIOD, CANYON COUNTY, IDAHO

Qty Multi-Mover	Qty Crawler Tractor	Total Hour Capacity Available		Hour Capacity Used		Percentage Used		Cost			Total Cost ($)
		Multi-Mover (hr)	Crawler Tractor (hr)	Multi-Mover (hr)	Crawler Tractor (hr)	Multi-Mover (%)	Crawler Tractor (%)	Multi-Mover ($)	Crawler Tractor ($)	Rental ($)	
2	0	2,520	0	2,151	0	85.4	0	24,786	0	0	24,786
1	0	1,260	0	1,508	0	119.7	0	17,225	0	31,372	48,597
1	1	1,260	1,260	1,508	1,506	119.7	119.5	17,153	14,214	2,728	34,095
1	2	1,260	2,520	1,508	1,564	119.7	62.7	17,225	14,260	0	31,485
0	1	0	1,260	0	1,501	0	119.1	0	13,992	52,024	66,016
0	2	0	2,520	0	3,023	0	120.0	0	28,594	24,909	53,503
0	3	0	3,780	0	4,211	0	111.4	0	39,221	0	39,221

TABLE 31

SUMMARY OF RESULTS - SUMMER PERIOD, CANYON COUNTY, IDAHO

		Total Hour Capacity Available		Hour Capacity Used		Percentage Used		Cost			
Qty Multi-Mover	Qty Crawler Tractor	Multi-Mover (hr)	Crawler Tractor (hr)	Multi-Mover (hr)	Crawler Tractor (hr)	Multi-Mover (%)	Crawler Tractor (%)	Multi-Mover ($)	Crawler Tractor ($)	Rental ($)	Total Cost ($)
2	0	1,224	0	1,118	0	91.3	0	12,726	0	0	12,726
1	0	612	0	727	0	118.8	0	8,485	0	14,458	22,943
1	1	612	612	727	731	118.8	119.4	8,485	6,665	2,523	17,673
1	2	612	1,224	647	765	105.7	63.9	7,565	6,975	2,523	17,063
0	1	0	612	0	732	0	119.6	0	7,205	26,577	33,782
0	2	0	1,224	0	1,467	0	119.9	0	13,976	12,071	26,045
0	3	0	1,836	0	2,107	0	114.8	0	19,887	0	19,887

costing $9.09/hr, was not used to capacity. These costs do not appear in Table 29, but are input parameters discussed previously. This apparent discrepancy is caused by the travel time to the remote site being more significant with the increased service frequency (decreased service time per visit) of summer operation. The base for rental equipment is not known, so only the time at the site is charged. Perhaps a flat charge for travel should be added for rental service.

Table 32 summarizes the allocation of costs to each site for the three cases that were found to have sufficient capacity.

Market Potential. A survey of sparsely populated counties was made to determine the degree of interest in the Multi-Mover. Questionnaires were mailed to a 15% random sample of counties having a population of 100,000 or less and an area of at least 300 square miles. One hundred and thirty-three of the questionnaires were returned with 86 indicating that their county either did not maintain a disposal operation or operated burning dumps only. Of the 47 respondents that operated some type of landfill disposal operation, 19 (40%) expressed an interest in the Multi-Mover after reading a brief description of the machine's capabilities. Forty-nine percent said they were not interested and 11% did not respond to the question.

A similar survey was made of 111 small cities and towns in the Pacific Northwest and Northern California. Fifty-six percent of the questionnaires were returned, and of the

TABLE 32

SUMMARY OF SITE COST

Qty Multi-Mover	Qty Crawler Tractor		Lake Lowell	Middleton	Central Cove	Parma	Melba	Total
2	0	Winter	$ 16,100	$ 2,306	$ 2,344	$ 3,552	$ 484	$ 24,786
		Summer	7,820	1,462	1,224	1,870	350	12,726
		Total	23,920	3,768	3,568	5,422	834	37,512
1	2	Winter	$ 21,896	$ 2,759	$ 2,448	$ 3,870	$ 512	$ 31,485
		Summer	10,655	1,772	1,448	2,830	350	17,063
		Total	32,551	4,531	3,896	6,708	862	48,548
0	3	Winter	$ 27,125	$ 3,233	$ 3,424	$ 4,695	$ 744	$ 39,221
		Summer	13,175	1,938	1,768	2,516	490	19,887
		Total	40,300	5,171	5,192	7,211	1,234	59,108

62% which responded to a question regarding interest in the Multi-Mover, 44% were interested and 56% were not. Failure to answer this question was frequently explained with comments indicating the respondent was not responsible for the actual operation of the disposal site and was not in a position to judge the equipment requirements.

The questionnaires requested comments on the practicability of the Multi-Mover concept. Negative comments questioned the practicability of rubber tires for landfill use and the reliability of a machine as complex as the Multi-Mover. The high expected purchase price also received unfavorable comments. The positive comments praised the versatility of the machine.

Comments regarding presently used equipment were also requested. Most of these constituted complaints of excessive repair and maintenance costs for track-type vehicles. Several respondents mentioned the crawlers' tendency to pick up wire in the undercarriage, which causes downtime and repair bills.

Battelle-Northwest's surveys indicate that the demand for the Multi-Mover will exist primarily among disposal site operators using either modified or sanitary landfill techniques. Only one of the open dump operators surveyed expressed an interest in the Multi-Mover, and he noted that his operation was being converted to sanitary landfill and required additional equipment. The number of landfills currently in operation or in the planning stage should be a measure of the potential market for the Multi-Mover. There are now approximately 90,000 recognized land disposal sites in the U.S. and approximately 12,000 of these are identified as sanitary by local agencies.(4)* The surveys show approximately 42% of the landfill operators surveyed to be interested in the Multi-Mover for their operations. Applying this ratio to the 12,000 landfills in the United States yields an interest potential for approximately 5,100 units. The remaining 78,000 recognized disposal sites are open dumps. As public opinion and health and environment standards become less tolerant of this method of disposal, most of the dumps will be either closed or converted to sanitary landfills. In either case, additional earthmoving equipment will be required. Applying the 42% interest ratio to these 78,000 sites yields approximately 33,000 operators who would be interested in the Multi-Mover. Of course, these dumps will be converted or replaced over a period of many years.

It is not expected that each interested landfill operator would actually purchase a Multi-Mover or that each purchaser would make his purchase immediately. If we assume that one Multi-Mover could be sold for every five interested landfill operators (over a period of five years), we have a potential market of just over 1,000 machines. This does not include the effect of conversion of dumps to new landfills, which could provide a potential market of an additional 6,800 machines over a period of several years.

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* EPA Comment: The identification of 12,000 land disposal sites as "sanitary" is apparently not correct; the National Survey indicates there are presently less than 1,000 true sanitary landfills.

The projections of the potential market for Multi-Movers consider only the solid waste industry. The versatility and adaptability of the machine could make it useful for road construction, mining, or general construction. The machine should be evaluated for these uses and the market potentials assessed.

These estimates are based on several implicit assumptions. The production model Multi-Movers would have to live up to performance expectations and both the machine and the manufacturer would have to gain satisfactory reputations in the field. Successful marketing of the machine will depend heavily on the reputation of the manufacturer, since many operators consider parts availability and service to be very important factors in their choice of equipment. They also want to assure themselves as much as possible that the equipment will be available when needed and not down for repairs, and therefore, rely heavily on personal experience and manufacturer reputation.

It is not within the scope of this study to evaluate in detail all of the factors affecting the potential market for the machine. The above estimates, however, are sufficiently precise to indicate a valid and significant potential market for the Multi-Mover. This market will tend to increase in the next 5 to 10 years as the number of sanitary landfills increases in response to increasing concern for the quality of the environment. Although alternative disposal methods will account for an increasing share of our solid wastes, the landfill's low cost and adaptability will assure its continued importance in the solid waste program. The potential market for Multi-Mover should also steadily increase for at least several years.

Systems Analysis of Solid Waste Disposal in a Sparsely Populated Area. The problems of solid waste generation, collection, transportation and disposal in a sparsely populated area are not fundamentally different from those of a densely populated metropolitan area. In both cases, the primary objective of a solid waste program is to provide the maximum solid waste disposal service within the limitations of law, funding, and public demand for services. The tasks which must be completed to meet this objective are basically the same in either a sparsely or densely populated area. The citizens must be educated to store their waste in such a way as to minimize health hazards and aesthetic blight, and the waste must be collected and transported from its point of generation to some central location for reclamation or disposal. These three major steps reduce to many different tasks and the proper execution of each of these tasks becomes a problem for the agency(s) charged with the responsibility of administering the solid waste program in a given area. Although the problems encountered are similar for densely and sparsely populated areas, the relative importance of the various problem areas depends on the population density. This section defines some of the problem areas that are likely to be particularly important in a sparsely populated area and examines solutions to these problems. Particular emphasis is placed on ways that a multi-functional machine (such as the Multi-Mover) might contribute to the solution of these problems.

The 1970 Census classes 57.1% of the 61,288 Canyon County residents as urban (i.e., residing in incorporated cities of 2,500 or more). The urban residents live in the cities of Caldwell, Nampa, and Parma. The average population density for the entire county is approximately 120 people per square mile, but if the cities of Nampa and Caldwell are excluded, this drops to approximately 69 people per square mile for the rest of the county. The cities of Nampa and Caldwell have ordinances for compulsory pickup of household refuse by franchized collection agencies. Contract collection service is available in some other parts of the county, but many of the people living outside of these two cities must dispose of their solid wastes themselves.

Areas considered as sparsely populated may differ considerably from Canyon County; however, in the context of this report the primary criterion for a sparsely populated area is that its solid waste collection and disposal operations are hampered by low population density. Although no two sparsely populated areas are exactly similar in terms of population distribution and solid waste disposal problems, use of a typical example facilitates the discussion of some of these problems.

Description of a Typical Solid-Waste Disposal System. The solid-waste disposal system in a sparsely populated area includes all the steps of handling solid waste from the time it leaves the point of generation (the housewife's kitchen garbage pail, or the merchant's trash barrel) to the time of its disposal or recycle. Common practice in sparsely populated areas at the present time is to dispose of the wastes in some type of open dump or landfill. Figure 15 shows the most common possibilities of solid waste generation, transportation, and disposal in a sparsely populated area. This flow chart shows only the solid waste bound for disposal in a solid-waste disposal operation. It does not include solid waste which is reused, or recycled. For example, a significant amount of solid waste from food processing operations is used by nearby feedlots and does not enter the county solid waste system.

A sparsely populated area is not likely to provide collection service to all the producers of solid waste. In Canyon County, for example, there is compulsory collection service in the cities of Caldwell and Nampa, and collection services are available in the towns of Parma, Notus, and Wilder for those residents who wish to contract for this service. There is no organized collection service available to approximately 40% of the residents of the county. Many of the residents

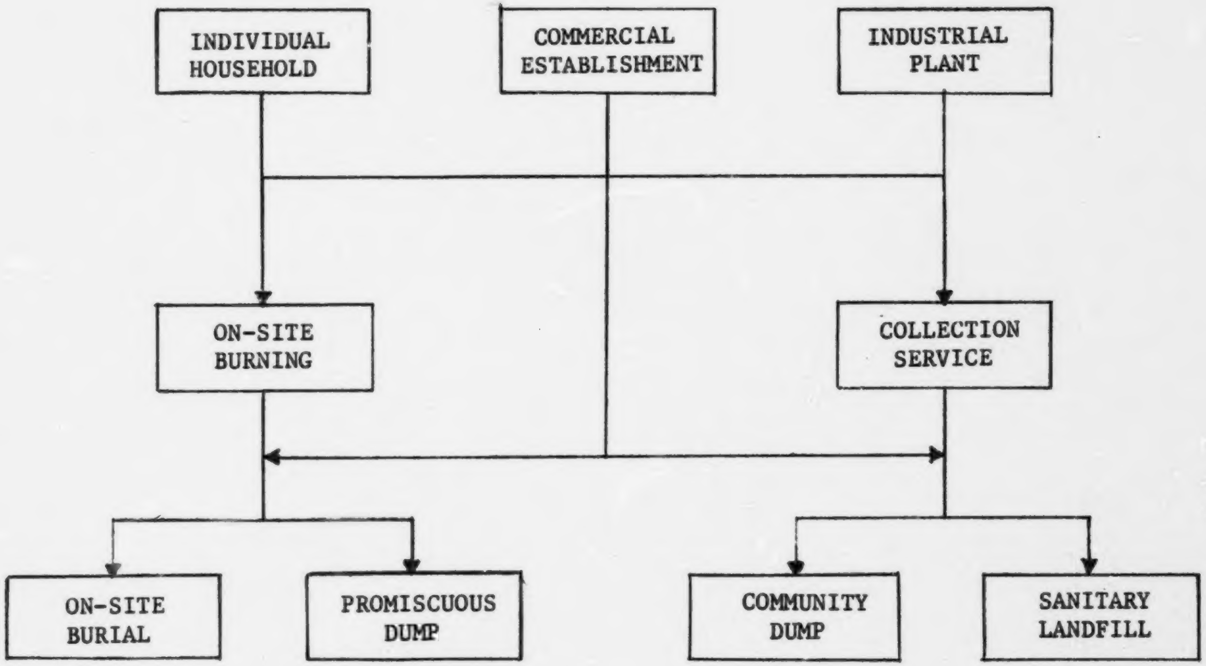
INDIVIDUAL HOUSEHOLD
COMMERCIAL ESTABLISHMENT
INDUSTRIAL PLANT
ON-SITE BURNING
COLLECTION SERVICE
ON-SITE BURIAL
PROMISCUOUS DUMP
COMMUNITY DUMP
SANITARY LANDFILL

Figure 15. Solid Waste Disposal System in Sparsely Populated Areas

in areas where collection service is available do not take advantage of the service, but prefer to handle the disposal of their household refuse themselves. In addition, many of the processors of commercial and industrial solid waste also handle their own disposal operations. There are several possibilities open to those residents and industries who either must handle their own solid waste disposal or elect to do so rather than availing themselves of a collection service. Many residents simply collect their household refuse and periodically transport it to a county operated disposal site. Other residents elect to burn the combustible portion of their refuse, collecting the ashes and noncombustibles for a later trip to a disposal site. Some rural residents dispose of their refuse by burying it on their own property, or by burning it and burying the ashes. Some residents simply dump their refuse wherever it is convenient, and in spite of "no dumping" signs and ordinances, promiscuous dumps are common in sparsely populated areas.

In the State of Idaho, the County Commissioners are responsible for establishing and operating sufficient solid waste disposal sites to provide convenient access for all citizens of the county. The State Board of Health is responsible for adopting and promulgating rules and regulations governing the operation of the disposal sites, and the Boards of County Commissioners must provide ordinances governing the use and operation of the sites within the State's regulations.

The cities are allowed to operate disposal sites subject to the same rules and regulations as the county. Any private land owner must obtain a written permit from the Board of County Commissioners to dispose of solid waste on his own property. The counties are allowed to fulfill their responsibilities by several possible means: they may operate disposal sites themselves, they may enter into joint operations with cities or other counties, or they may contract with private firms to operate the sites. The counties may finance solid waste disposal operations by using current revenues; by levying taxes; by charging fees for the use of the disposal facilities or by receiving and expending monies from any other source, or both.(5) A typical governmental organization of solid waste operations is shown in Figure 16.

Major Problem Areas. Whether any part of a solid waste disposal system is described as a problem area often depends on the observer's point of view. For example, a person familiar with solid waste disposal in a large, densely populated metropolitan area would not be likely to consider site acquisition in a sparsely populated area a very serious problem. To the County Commissioner faced with finding a suitable disposal site in a convenient location at a reasonable price, this may be a very serious problem. This example, then, emphasizes that the term "problem area" is subjective. The situations to be discussed are defined as "problem areas" only because they are most likely to be major stumbling blocks to either efficient or cost effective operation of a solid waste program in a sparsely populated area.

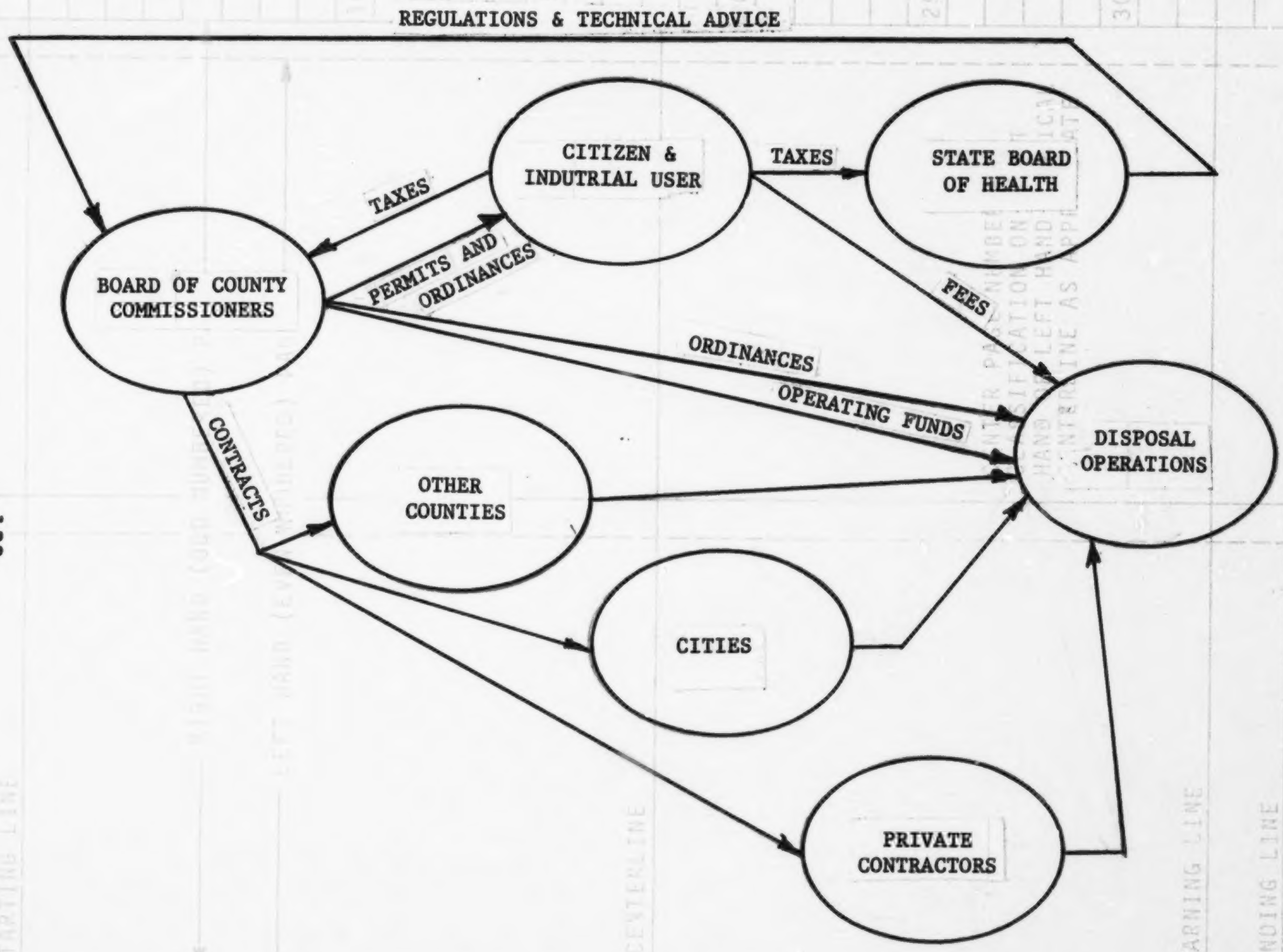
REGULATIONS & TECHNICAL ADVICE
CITIZEN & INDUTRIAL USER
TAXES
STATE BOARD OF HEALTH
TAXES
PERMITS AND ORDINANCES
BOARD OF COUNTY COMMISSIONERS
FEES
ORDINANCES
OPERATING FUNDS
CONTRACTS
OTHER COUNTIES
DISPOSAL OPERATIONS
CITIES
PRIVATE CONTRACTORS

Figure 16. Idaho Governmental Organization of Solid Waste Disposal Operations

The definitions of problem areas given in Table 33 might better be described in some cases as symptoms rather than problems. For example, problem areas of collection and earthmoving equipment capital and operating costs might be symptoms of a tax base which is inadequate to support the desired level of solid waste services. In any given situation, the optimum solid waste system will be achieved only by looking beyond the type of "problem areas" or symptoms listed in Table 33 and determining the underlying causes of these symptoms. It is meaningful to look at the various problem areas or symptoms and to discuss ways in which multi-functional machines may contribute to their solution, remembering that the treatment of symptoms alone will not solve any basic problem. After determining, for example, that the capital costs of earthmoving equipment that manifest as a problem are not just a symptom of poor financial management or an inadequate tax base, we may discuss methods of lowering capital costs with some assurance that any solutions we find will have a significant effect on the solid waste program.

Before discussing how the Multi-Mover may contribute to the solution of specific problems, it is necessary to discuss the general characteristics of the multi-functional machine and to compare it to other equipment currently in general use. The most commonly used equipment for small landfill

TABLE 33

RANKING BY SURVEY OF PROBLEM AREAS IN SOLID WASTE DISPOSAL OPERATIONS IN SPARSELY POPULATED AREAS*

Ranking Order	Affirmative Response (%)	Problem Area
1	58	Disposal site availability
2	52	Earthmoving equipment - capital cost
3	46	Blowing paper
4	44	Collection vehicle capital cost
5	36	Collection labor expense
6	36	Disposal of industrial or agricultural wastes
7	35	Haul distance to disposal site
8	33	Cover material availability
9	33	Earthmoving equipment - operating expense
10	31	Groundwater pollution
11	29	Customer cooperation
12	29	Disposal labor expense
13	28	Collection vehicle operating expense
14	15	Transportation - special handling problems
15	10	Collection frequency

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* From Battelle-Northwest Survey (described previously in this report) in response to the question "Which of the following do you feel are the major problem areas for a community such as yours?"

operations(such as those usually found in sparsely populated areas) is the crawler tractor equipped with either a bulldozer blade or a bucket loader. In some operations other equipment such as scrapers (either drawn by a crawler or self-powered), wheeled loaders and dump trucks are also used. In most cases the use of this additional equipment indicates the disposal operation is large enough to take advantage of this specialized equipment to achieve lower unit costs. Landfill operations which must use the minimum amount of equipment most often use a crawler tractor equipped with a loader attachment. This one piece of equipment is capable of performing all of the functions required for landfill operation such as digging trenches; moving and compacting waste; transporting, spreading, and compacting cover material; and maintaining haul roads. The crawler tractor with a bucket loader is reasonably efficient at excavating trenches and handling the wastes. It is less efficient in spreading cover material, and its efficiency decreases greatly with longer haul distances for cover material. When additional equipment is added to an operation, it is frequently a dump truck, scraper, or perhaps a wheeled loader to increase the efficiency of the hauling part of the operation. When this equipment is available to expedite hauling and excavation, a crawler tractor with a bulldozer or "trash blade" (a large bulldozer blade fitted with extensions to allow more waste to be pushed at one time) is often used instead of the front loader.

In the detailed cost-effectiveness comparison of the Multi-Mover and a typical crawler tractor included in this report, the Multi-Mover was found to be somewhat more expensive to own and operate, but its productivity is great enough to more than offset its higher cost, particularly where longer haul distances are involved. The Multi-Mover was quicker in transport from site-to-site for distances less than 21 miles, and less expensive to transport for distances less than 12 miles. Each of the major problem areas is analyzed in light of the results of the cost-effectiveness analysis to determine whether the Multi-Mover would help to solve the problem.

A mail survey of city and counties in sparsely populated areas was used to determine the most important problems in solid waste operations (Table 33). The possible solutions to these problems were evaluated. The criteria for this evaluation were (1) the ability of the possible solution to increase the quality of solid waste service to a desired level at a reasonable cost and (2) to significantly reduce the cost of providing an already acceptable level of service.

One major difficulty facing the application of the first criterion was definition of a desired or acceptable level of service. This may be considerably different in a sparsely populated area than in an urban area and will also depend on the individual and collective viewpoints of the citizens. As an example, a man burning refuse in his backyard does not feel there is a pollution problem (as long as there is a breeze blowing) but obviously his next door neighbor may have a very different opinion. Many sparsely populated areas have solid waste conditions which they feel are entirely adequate, but which would be wholly unacceptable in a more densely populated area.

The Problem of Low Population Density. Although it was not mentioned explicitly in the questionnaire, one of the most important factors affecting solid waste disposal in a sparsely populated area is the low population density, which tends to make solid waste service either more expensive or less convenient. Since the population is distributed over a wide area, it is difficult to take advantage of the economies of scale. A recent study(6) found that the cost per ton of waste disposed in landfills dropped markedly as the population served by the landfill increased. A survey of 120 landfill sites serving populations ranging from 10,000 to over 500,000 showed that the average cost per ton of waste dropped from $1.62 for an operation serving 10,000 people to $0.90 for one serving 40,000, and $0.25 for an operation serving a population of 500,000 or more.* Collection service also tends to be more expensive because of the greater distances between residences, and therefore is not generally available in sparsely populated areas.

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* EPA Comment: These reported disposal costs are probably lower than could normally be expected for sanitary landfill operations.

The problem of services being more expensive because of the low population density is frequently compounded by an associated inadequate tax base, which often cannot support the required services. The fact that the economy is generally agriculturally oriented with minimal industrial development contributes to the inadequate tax base. Often the people in sparsely populated areas are not as concerned about solid waste problems as their urban or suburban counterparts. This lack of concern is usually reflected in the governing body of the area, and attempts to increase taxes to improve solid waste disposal are not likely to be politically rewarding actions.

The effects of the typical lack of universal collection in sparsely populated areas are many. In every case these effects accrue to the historical lack of personal responsibility on the part of many citizens when they are charged with an unenforced social responsibility that represents a personal inconvenience. This is shown in the continuing existence of residential burning, promiscuous dumping, indiscriminate burial, and poor containment during storage and hauling of solid wastes on the part of individuals. And while universal collection service for all residents of the area would eliminate most of the effects, the costs of providing such a service would be high. It is expected that a significant percentage of the residents would not be willing to pay such costs, preferring to continue handling their own solid waste disposal.

An alternative to universal collection is to make proper waste disposal as convenient as possible. This requires that disposal facilities be available within a reasonable distance from each residence in the area. The most widely practiced alternative is to scatter small dumps or landfills, or both, about the area so that no resident must drive too far to reach one. Since each of these disposal sites serves only a relatively small population, it is usually not economically feasible to operate them as sanitary landfills. An acceptable compromise is to operate them as modified landfills or community improved dumps with service on a rotating basis.* The drawback of this approach lies in the expense of their operation. In most instances the sites of this type are not operated as modified landfills, or even as improved dumps, but rather as open or burning dumps, thereby nullifying many of the reasons for their existence.

In most cases it is considerably less expensive to maintain one disposal site to serve the population of an area than to operate the several. A possible method of realizing the economies afforded by one large operation while still retaining the advantages of conveniently located disposal facilities is the use of transfer stations. In this type of system, a number of receptacles are strategically placed about the service area. The residents bring their refuse to these receptacles, from which refuse is periodically transferred to a central disposal site. There are many types of transfer systems using this approach. Most consist of a large bin which is either lifted onto a special truck chassis and hauled to the disposal site to be emptied or emptied into a specially constructed compacting truck, which services several bins before going to the disposal site. The bins may be equipped with devices to compact the refuse as it is dumped into them, extending the time between emptyings. A recent study(7) made by the California State Department of Public Health and the Consulting Firm of Elmendorf, Zinov, and Rubin investigated the feasibility of such a system for use in Humboldt County, California. Humboldt County is located in the coastal Redwood Forests of California and has an overall population density of less than 30 people per square mile. After considering such alternatives as extension of house-to-house collection, containerized storage and transfer facilities, local disposal sites, central sanitary landfills, incineration, composting and pyrolysis, an advisory committee determined that modified sanitary landfills dispersed throughout the county and serviced by mobile crews or containerized transfer operations were the only feasible alternatives. These alternatives were then studied in some detail to determine the probable costs of each system. Two containerized transfer systems were studied, one using 40-yd^3 drop boxes and noncompacting collection vehicles, and the other using 8-yd^3 bins and compaction-type collection vehicles. The modified landfill system was found to be more expensive than either of the containerized systems.

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* See EPA Comment on page 117.

The principle advantages of a system of modified landfills are low initial cost and the ability to dispose of all types of solid waste. The disadvantages include the difficulty in finding suitable sites in locations most convenient to the citizens, the problems of environmental pollution and aesthetically offensive appearance, and inefficient use of the site because of ineffective compaction. The advantages of a container system include few restrictions on container location and reduced environmental pollution since the waste is disposed of in one well-run sanitary landfill. Its biggest disadvantages include the high initial equipment cost and the limited types of refuse accommodated (only refuse which is small enough to pass through the container opening can be handled).

Determination of the superior system depends on many factors, including costs of site acquisition and preparation for both systems, the terrain and the highway system in the area, the desired level of service, availability of capital and operating funds, the minimum standards for operating the disposal sites, the existing disposal sites, and the type of bins being considered. Only a detailed analysis of each situation can determine the most effective system. In some sparsely populated areas, other methods of solid waste disposal might prove more feasible than either the system of scattered landfills or the transfer operations, and all potential systems should be considered in view of the specific circumstances of a particular area.

One alternative to making disposal operations more efficient is reducing the amount of waste for disposal. Since the cost of disposal operations depends on the amount of waste to be disposed, any possible reuse or recycling opportunities should be carefully considered as a part of the evaluation of a solid waste program. Several factors exist to encourage this approach, including a growing public awareness of the inevitable environmental degradation resulting from present methods of waste disposal and the increasing concern for conservation of our limited natural resources. It is conceivable, for example, that the savings in disposal costs might be greater than the cost of an incentive program to promote the recycling of some types of waste.

Sanitary and modified landfill operations will continue to be a popular and suitable means of solid waste disposal for some time in sparsely populated areas where suitable landfill sites are available and the tax base does not favor large capital outlays. Therefore, it is appropriate to determine ways in which a multi-functional machine such as the Multi-Mover might help to improve service or lower costs, or both.

It is not helpful to evaluate the Multi-Mover using generalities such as "The multiple capabilities of the machine should contribute to increased efficiency, since one machine can do the same operations as four separate machines." Any useful evaluation must determine whether a given job can be done more economically by the Multi-Mover or by some other type or combination of earthmoving equipment. In the following analysis the Multi-Mover is compared with a crawler tractor equipped with a 1-1/4 yd^3 general purpose bucket. This machine is reasonably typical of the equipment currently used for landfill operations in sparsely populated areas.

Disposal Site Availability. Disposal site availability appears to be the most widely felt problem, since it was mentioned by 58% of the respondents to the questionnaire. The problems related to the acquisition of disposal sites include (1) the lack of area (more precisely, usuable volume) sufficient to handle the projected waste input for a reasonable length of time, (2) zoning ordinances prohibiting landfill operations, (3) unreasonable haul distances from the population center(s) served, (4) lack of accessibility from population centers without creating heavy truck traffic through residential areas, (5) nonavailability of suitable on-site or nearby cover material, (6) potential of ground and surface water pollution, (7) need for suitable separation from existing residential and commercial developments, (8) prohibitive real estate prices, and (9) public acceptability of the site.

One of the most straightforward approaches to the problem of disposal site availability is to make more efficient use of each available site. If more waste can be disposed in a site, it will have a longer useful lifetime. Smaller sites are generally easier to find and less expensive than larger sites. This may mean an available parcel of land suitable for landfill service may be used in spite of its small size. In addition, higher refuse densities usually result in more rapid stabilization of the fill, thereby making it available for other uses sooner after completion of the landfill operations. Battelle-Northwest's studies indicate the Multi-Mover is capable of higher compaction ratios than the crawler tractor under similar conditions, with observed compaction ratios of approximately 4.2:1 and 2.1:1, respectively. Thus, under these test conditions, about 100% more waste may be disposed in a given site by using the Multi-Mover for compacting.

Maximum use of available land is one reason for operating a disposal site as a sanitary landfill. An open dump operates at essentially a one-to-one compaction ratio (trucked volume/in-place volume). In sanitary landfills, which are compacted and covered daily, average compaction ratios from 2:1 to 3:1 are achievable with conventional crawler tractors, and with the Multi-Mover, ratios as high as 4:1 are possible at a reasonable cost. A dump that is covered periodically might typically consist of one part earth cover for each ten parts waste, while a sanitary landfill typically consists of one part cover for each four parts waste. Even though more cover is included, a landfill operating at a 3:1 compaction ratio can store approximately 2.6 times as much waste per acre-foot as a covered dump.

The Multi-Mover can haul cover material for moderate distances at a lower cost than the crawler tractor. For example, the cost of moving cover material 500 ft from stockpile to cell with the Multi-Mover is estimated at \$0.24/yd^3. The cost using the crawler tractor is estimated at \$0.58/yd^3. Both estimates include capital costs, operating expenses, and the operator's wages.

A reduction of cost in any part of the landfill operation may be considered as contributing to the solution of the other cost-related problems. For example, if the Multi-Mover results in lower overall cost because of higher productivity, the savings could be used to balance the cost of acquiring a new site. This relationship may not exist in some counties. In many cases, operating costs must be paid from the county's general fund and site acquisition must be financed by bond issues. However, the savings can be applied to some operating account. This indirect relationship is assumed to be implicit in each of the following discussions.

Earthmoving Equipment -- Capital Cost. The capital cost of earthmoving equipment for landfill use was considered a major problem by 52% (Table 33) of the respondents in the survey. The analysis of this problem in relation to the Multi-Mover is complicated by the financial circumstances of the purchase and individual earthmoving equipment requirements. Many of the landfills in sparsely populated counties are operated by city and county governments. Although the financial circumstances among similar units of government vary widely, they generally purchase large capital items by voter-approved bond issues and pay operating expenses from the general fund. Since voters are seldom enthusiastic about bond issues, equipment with a low capital cost is usually preferred to more expensive and efficient equipment. Even though the Multi-Mover is more efficient and would have a longer usable life than a crawler tractor, the Multi-Mover's higher capital cost is a negative factor. In the case where all of the Multi-Mover's capacity is required to maintain the desired level of service, the situation would be slightly different. Several crawler tractors and other earthmoving equipment would be required to meet the productivity of the Multi-Mover. In a case where the total capital expenditures for the required equipment are approximately equal, the measure of cost/unit work performed becomes the most important selection criterion. The Multi-Mover's cost/unit work is lower than that of the crawler tractor under most operating conditions. It must be emphasized that the above comments deal with tendencies and that actual financial decisions, even under apparently similar circumstances, will depend to a great extent on local policies and the idiosyncracies of the individuals involved in the purchase decision.

Blowing Paper. Forty-six percent of the respondents to the survey indicated blowing paper was a major problem. The Multi-Mover would not contribute directly to the solution of this problem.

Collection Vehicle Capital Cost. The capital cost of collection vehicles was the fourth most often mentioned major problem. The Multi-Mover might contribute to the solution of this problem only where both the collection and disposal operations are operated by the same entity and the savings in the disposal operation costs could be applied to the purchase of collection vehicles. As discussed previously, governmental capital outlays are often financed from bonds rather than from the general fund, and it is doubtful in many cases that the savings in operating costs could be applied to capital expenditures.

Collection Labor Expense. Collection labor expense was a major problem to 40% of survey respondents. The Multi-Mover might lower collection labor expenses in one or more ways. The Multi-Mover's superior compaction ability might make feasible the use of smaller, more advantageously located disposal sites. This would reduce collection labor expense by reducing the slack time spent by collection crews during trips to and from the disposal site. Also, the Multi-Mover's flexibility and capability for highway travel might make feasible the operation of additional disposal sites at convenient locations. At best, these are possibilities for secondary effects and in themselves would not constitute a direct advantage in the use of the Multi-Mover.

Disposal of Industrial or Agricultural Wastes. Thirty-six percent of the respondents considered the disposal of industrial and agricultural wastes to be a major problem. In sparsely populated areas, agricultural wastes are more likely to be encountered than industrial wastes. The Multi-Mover would make no direct contribution to the solution of this problem.

Haul Distance to Site. Haul distance to the disposal site was considered a major problem area by 35% of the respondents. The Multi-Mover could perhaps influence the choice of a new site. (Disposal Site Availability, see page 149.)

Cover Material Availability. Thirty-three percent of the respondents felt the availability of suitable cover material is a major problem. The Multi-Mover could contribute in cases where the amount of cover material to be hauled and the haul distance are not sufficient to support the cost of a scraper or a loader and dump truck, but where the distance to the cover supply is too great for the economical use of the crawler tractor.

Earthmoving Equipment -- Operating Expense. The operating expense of the earthmoving equipment required to operate a landfill was cited as a major problem by 33% of the respondents. According to Battelle-Northwest estimates of hourly operating costs and productivity for the Multi-Mover and the crawler tractor, the Multi-Mover should be able to significantly reduce the operating expenses. The hourly operating cost of the Multi-Mover is slightly higher than that of the crawler tractor. However, the higher productivity of the Multi-Mover more than compensates for its higher hourly costs. Table 34 summarizes the machine operating costs for the Multi-Mover and crawler tractor on a cost-per-unit work basis. The cost estimates include only the variable machine operating expenses such as fuel, lubricants, hydraulic fluid, repairs, maintenance and overhauls, and do not include any allowance of depreciation, interest, insurance, taxes or operator's wages.

For three of the tasks the cost/unit work depends on the haul distance involved. For short distances the faster loading time of the crawler tractor makes it less expensive to operate. However, for longer haul distances, the higher speed and greater carrying capacity of the Multi-Mover make it more economical on a work per dollar basis. The breakeven points (distance where the operating cost/unit work is equal for the two machines) are given in Table 35.

TABLE 34

SUMMARIZED COST/UNIT WORK COMPARISONS OF MULTI-MOVER AND CRAWLER TRACTOR

Operation	Multi-Mover ($)	Crawler Tractor ($)
Cost per operating hour	3.22	3.04
Excavate cell(1)	(0.04 d + 48.30)/ 1000 yd^3	(0.32 d + 32.93)/ 1000 yd^3
Spread waste	8.94/1000 yd^3	19.50/1000 yd^3
Compact waste	7.24/1000 yd^3	12.07/1000 yd^3
Spread cover (excavated)(1)	(0.04 d + 48.30)/ 1000 yd^3	(0.32 d + 39.68)/ 1000 yd^3
Spread cover (stockpiled)(1)	(0.05 d + 39.35)/ 1000 yd^3	(0.32 d + 32.93)/ 1000 yd^3
Compact cover	0.10/1000 ft^2/pass	0.14/1000 ft^2/pass
Travel between sites	0.23/mile	0.124/mile

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(1) d = one-way haul distance in ft.

TABLE 35

OPERATING COST/UNIT WORK BREAK-EVEN DISTANCES

Task	Break-Even Distance
Excavate trench	55
Spread cover from excavation	31
Spread cover from stockpile	24

Groundwater Pollution. Thirty-one percent of the respondents considered groundwater pollution to be a major problem. The Multi-Mover however, would not contribute directly to the solution of this problem.

Customer Cooperation. Twenty-nine percent of the respondents felt that their customers' cooperation was a major problem. Customer cooperation is important both in providing suitable containers for home storage of refuse and in operating a disposal site in an acceptable manner. The Multi-Mover will have little effect on any attempts to improve customer cooperation. It is possible that improved disposal operations (the site carefully policed and maintained, cover applied frequently, etc.) would encourage customers to be more cooperative.

Disposal Labor Expense. Disposal labor expense was cited by 29% of the respondents as a major problem. At small sanitary landfills, most improved dumps, and modified landfills, the equipment operators' wages and benefits usually account for the total disposal labor expense. At the larger sanitary landfills, however, disposal labor expense would include the wages of gatekeepers, supervisors, laborers and equipment operator(s). Since the Multi-Mover is faster than the crawler tractor at performing some of the basic landfill operations (depending on the situation at the particular landfill), a reduction in the labor expense should occur in one or more of the following ways: (1) the operator will be needed for fewer hours per week (elimination of overtime, use of a part-time operator, and the use of operator and machine at other sites are possibilities), (2) the operator will be able to devote part of his time to other functions such as policing the site or handling gatekeeping duties during off-peak periods, and (3) the operator will be able to devote more time to the normal operations, thereby improving the quality of the disposal operation (perhaps achieving better overall compaction efficiency and thus increasing the useful life of the site).

Collection Vehicle Operating Expense. Twenty-eight percent of the respondents considered the operating expense of collection vehicles to be a major problem. The Multi-Mover would have no direct effect on the operating expense of collection vehicles. However, it might have a small effect on the maintenance and repair expenses of a collection vehicle because it produces a smoother and more solid compacted cover lift over the area where trucks drive before unloading, which should also reduce the likelihood of trucks becoming stuck on the landfill. The Multi-Mover could reduce collection vehicle expenses by permitting the use of a more convenient disposal site.

Canyon County Resource Base. The purpose of examining Canyon County's resource base is to identify those resources on which future county employment and income depend, to project Canyon County's economy to 1990, and to assess the projected impact of these on solid waste generation. This analysis concentrates on the natural resources of Canyon County, their general degree of development, and their potential for influencing future economic growth in the county; the County's current and future industrial base; and the County's service industry trends. The results form the basis for projecting future county population, economic profile and solid waste generation.

Natural Resources. Canyon County encompasses an area of approximately 580 square miles, or 371,200 acres.(8) It is one of the smallest counties in the State of Idaho, where the average county size is 1,880 square miles. The county itself is located in the Southwest portion of Idaho with much of its eastern and southern border along the Snake River. The relatively flat land supports agriculture but is semiarid and receives insufficient rain during the growth season to support farming without irrigation. The county has within, or along, its boundaries the Snake and Boise Rivers, which provide much of the water used for irrigation. The 1964 Census of Agriculture indicates that of the 190,500 acres of crop plant harvested, 189,674 acres were irrigated. Most of the reasonably farmable land within the county is now being farmed. Only moderate expansion of sprinkling systems is foreseen for the dry land farms, which total a small area in comparison to the land now being irrigated.

Of the two primary sources of irrigation water, the Snake River forms the southern as well as a large part of the eastern border of the county, and the Boise River cuts across the county from east to west. The Boise River primarily serves water diversion projects, both publicly and privately developed, with little pumping of its waters. On the other hand, little water is diverted from the Snake River, while considerable quantities of water are pumped from it. In some instances water is pumped to 500 feet above the river elevation. Canyon County also derives significant quantities of water for irrigation from deep wells. In view of the highly developed irrigation system in Canyon County, it is expected that only moderate expansion of the present system will take place over the next 20 years.

Most of the metallic and nonmetallic mineral resources of Canyon County offer prospects for only small economic growth. Such nonmetallic minerals as sand, gravel, limestone, and pumice are commercially quarried for the local county market. Currently, there is no known commercial mining of metallic minerals in the county. Mineral production for 1968 was slightly over $1 million with sand and gravel providing the greatest income, followed by lime then pumice. The 1968 sales were 20% below the revenues from 1967 primarily because of a decline in sand and gravel revenues. The reason given for this decline was the reduced requirement for these materials in state highway department projects. The volcanic scoria pumice produced in the county is used mainly as light-weight aggregate in precast concrete construction products with smaller quantities used as roofing rock and landscape materials.

Agricultural Complex. Canyon County ranks fifth among Idaho counties in the number of acres of cropland harvested in 1964 and leads all other Idaho counties with \$60 million of farm products sold annually (Table 36). This is approximately one-eighth of the state total and is almost equally divided between crops and livestock and livestock products. The importance of agriculture's direct contribution to the county economy is indicated in information developed by the Bonneville Power Administration,(9) which shows personal income from agriculture accounting for over \$17 million in 1961, or approximately 18% of personal income within the County. For the state as a whole, the same source indicates that agriculture accounts for about 12% of the personal income.

In the five year period between 1959 and 1964, farm product sales increased nearly 21% (Table 37). The largest absolute gain was an increase of almost \$5.9 million, or nearly 40%, in livestock and livestock products. Vegetables showed the largest percentage gain for the period with a 54% increase. Field crops increased by 26%. Three product areas showed a reduction in products sold between 1959 and 1964. Comparison of the 1959 and 1964 census of agriculture indicates

TABLE 36

CANYON COUNTY FARM PRODUCT SALES IN 1964*

Product	Sales	
Value of all farm products sold		$ 57,319,356
All Crops		$ 29,207,704
Field crops	$ 25,379,585	
Vegetables	1,511,073	
Fruit	1,776,229	
Forest and horticultural specialty products	540,817	
All livestock and livestock product		$ 28,111,652
Livestock and livestock product	$ 20,847,428	
Poultry and poultry product	1,063,949	
Dairy product	6,200,275	

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* From U. S. Department of Commerce, Bureau of the Census, 1964 Census of Agriculture

TABLE 37

CANYON COUNTY FARM PRODUCT SALES IN 1959 AND 1964*

Product	1959		1964		
	Value	% of Total	Value	% of Total	% Change
All farm products sold	$ 47,505,483	100.00	$ 57,319,356	100.00	20.7
Field crops	$ 20,076,537	42.3	$ 25,379,585	44.3	26.4
Livestock and livestock products	14,958,794	31.5	20,847,428	36.4	39.4
Dairy products	7,668,404	16.1	6,200,275	10.8	-19.1
Fruit	1,652,986	3.5	1,776,229	3.1	7.5
Vegetables	984,691	2.1	1,511,073	2.6	53.5
Poultry and poultry products	1,321,674	2.8	1,063,949	1.9	-19.5
Forest and horticultural specialty products	842,397	1.7	540,817	0.9	-35.8

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*From U. S. Department of Commerce, Bureau of the Census, 1964 Census of Agriculture.

that agricultural sales increased nearly $10 million between 1959 and 1964. Two product categories account for over 80% of the total value of the products sold in 1964. Field Crops have the largest value, followed by livestock and livestock products, but the order is reversed when one reviews the percentage growth in this period; livestock and livestock products have a percentage gain of nearly 40% and field crops show a gain of slightly over 26%.

Crops were harvested from 190,520 acres by Canyon County farmers in 1964. This is an increase of 10,881 acres, or 6% more than the number of acres harvested in 1959. The basic agricultural products harvested on these lands have been identified as alfalfa, the largest crop, followed by sugar beets, corn, wheat, and seed alfalfa (Table 38). It is interesting to note that Canyon County leads all other Idaho counties in the number of acres of sugar beets with nearly 18-1/2% of the sugar beet acreage in Idaho. On the other hand, Canyon County's 52,775 acres of alfalfa represent only 5% of Idaho's alfalfa acreage. Except for sugar beets, which increased production acreage from 22,124 acres in 1959 to 31,224 acres in 1964 and 37,000 acres in 1969,(10) other agricultural products have shown only moderate shifts in acreages.

Canyon County supports an intensified agricultural economy that is both diversified and mature. In addition, there appears to be only moderate shifting of crops, but from time to time

TABLE 38

LAND USAGE IN CANYON COUNTY IN 1964*

		Acres
Land area		371,200
Cropland Harvested	**Acres**	
		190,520
Corn	18,018	
Wheat	16,348	
Oats for grain	2,764	
Barley	8,370	
Mixed and other grains	11,024	
Alfalfa	52,775	
Clover	2,728	
Other hay	1,881	
Seed alfalfa	15,967	
Seed clover	2,849	
Irish potatoes	8,487	
Dry field beans	4,911	
Sugar beets	31,224	
Sweet corn	4,319	
Dry field peas	131	
Vegetables	5,456	
Fruit and grapes	4,732	
Counted twice	1,460	
Cropland not harvested		7,735
Woodland		450
Pasture		104,987
Public and other land usage(1)		67,548

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* From U. S. Department of Commerce, Bureau of the Census 1964 Census of Agriculture.

(1) Public lands include the following recreational acreages: Federal 11,000; State 1,541; County 65; Municipal 360 . Phone Conservation, Bureau of Outdoor Recreation, December 1970.

crop market conditions or disease problems may accentuate shifting specific crops. Such has been the case in recent years with curly tops in sugar beets. However, with the introduction of resistant varieties of sugar beets, production of this crop is expected to grow moderately over the next 20 years. Expansion in sugar beet production between 1960 and 1968 has nearly doubled. This is attributed largely to the termination of sugar imports from Cuba in 1960 and has resulted in re-allotment of Cuban sugar production to domestic producers. Production of sugar beets in Idaho and Canyon County for the next 20 years is expected to relate closely to the growth in national consumption of sugar. Thus, the general agricultural economy of Canyon County shows only moderate crop production growth prospects, limited by the small amount of expandable farm land available, and a farily mature crop mix. Prospects for livestock growth appear better, but only moderate production increases are foreseen for the period from 1970 to 1990.

For the five year period from 1963 to 1968, agricultural employment in Idaho decreased at a rate of 2.8%/yr while agricultural employment in Canyon County increased nearly 1.3%/yr. Mechanization of farm work will continue, resulting in a decrease of agricultural employment in relation to agricultural output. Agricultural employment in Canyon County will first stabalize then begin to decline late in the period. Projected 1980 agricultural employment is 5,300, while 1990 agricultural employment in Canyon County is projected to be 4,800.

Industrial Base. Although agriculture is a basic employer in Canyon County a shift toward the food processing industries is occurring. Therefore, food processing is expected to continue to have a significant impact on the economy of the county.

Between 1963 and 1968, direct employment in food processing is estimated to have averaged 2,100 or 9.7% of the 21,700 total employed in the county. Agricultural employment accounted for another 5,100 jobs. The agricultural sector of Canyon County provided direct employment for one-third of the county's employed labor force.

In comparing Canyon County's agricultural and food processing employment to that of the State of Idaho, the most significant difference appears in the amount of labor force employed in food processing. Canyon County employs almost 10% of its labor force in this area, while the state averages only 5%. By 1969 employment in the food processing industries had grown to 2,940. Employment in Food and Kindred products manufacture is projected to be 3,300 by 1980 and 3,500 by 1990.

There is a useful system used to identify industries that have similar economic activities, this system is known throughout industry as the Standard Industrial Classification (SIC). The Standard Industrial Classification coding system is designed to cover the entire field of manufacturing activities, assigning to each manufacturer or establishment an industrial code on the basis of its major activity. The SIC number for a firm is usually determined by a product, a group of products produced or handled, or the services rendered. Thus, SIC numbers are structured so as to make it possible to classify establishments by industry on a 2-digit, 3-digit, or 4-digit basis according to the detailed information desired. Each 2-digit classification can have as many as ten 3-digit subclassifications. In a like manner, each 3-digit classification can have as many as ten 4-digit classifications. The manufacturing industry is divided into twenty-one 2-digit SIC classifications. The classification of manufacturing industries begins with SIC 19 and continues through SIC 39 (Table 39).

Table 40 provides a profile of Canyon County's manufacturing industries. The major 2-digit SIC categories of industrial products produced in Canyon County are provided as well as a more detailed 4-digit identification of specific product lines. The number of firms and the employment of these firms by employment classification codes are also provided in this table. Of the twenty-one 2-digit SIC manufacturing classifications, Canyon County supports industrial firms in 10 of these.

TABLE 39

TWO-DIGIT STANDARD INDUSTRIAL CLASSIFICATION OF MANUFACTURERS

SIC Code	Manufacturing Industries
19	Ordnance and accessories
20	Food and kindred products
21	Tobacco manufacturers
22	Textile mill products
23	Apparel and other finished products made from fabrics and similar materials
24	Lumber and wood products, except furniture
25	Furniture and fixtures
26	Paper and allied products
27	Printing, publishing, and allied industries
28	Chemicals and allied products
29	Petroleum refining and related industries
30	Rubber and miscellaneous plastics products
31	Leather and leather products
32	Stone, clay, glass, and concrete products
33	Primary metal industries
34	Fabricated metal products, except ordnance, machinery, and transportation equipment
35	Machinery, except electrical
36	Electrical machinery, equipment, and supplies
37	Transportation equipment
38	Professional, scientific, and controlling instruments; photographic and optical goods; watches and clocks
39	Miscellaneous manufacturing industries

From: Executive Office of the President, Bureau of the Budget, Standard Industrial Classification Manual, 1967.

TABLE 40

PROFILE OF CANYON COUNTY MANUFACTURING INDUSTRIES

	Manufacturing Industry	Number of Firms	Employment of Firm: Employment Classification Code*					
			1	2	3	4	5	6
20	Food and kindred products	32						
2011	Meat packing plants		7	0	2	0	1	0
2015	Poulty etc., packing		1+	0	1+	0	0	0
2021	Creamery butter		1+	0	0	0	0	0
2024	Ice cream, etc.		+	0	0	0	0	0
2026	Fluid milk		1+	0	0	1	0	0
2033	Canned fruit, vegetables, etc.		0	1	0	0	0	0
2037	Frozen fruit, vegetables, etc.		0	0	0	0	2	1
2042	Prepared feed for animals		4+	1	+	0	0	0
2051	Bread, bakery products		0	2	0	0	0	0
2063	Beet sugar		0	0	0	0	1	0
2094	Grease and tallow		0	1	0	0	0	0
2099	Food preparations NEC		1	1	0	0	0	0
24	Lumber and wood products	3						
2431	Millwork plants		1	0	0	1	1	0
25	Furniture and fixtures	3						
2512	Wood household furniture		1	0	0	0	0	0
2515	Mattresses and bedsprings		1	1	0	0	0	0
27	Printing, publishing,and allied industries	7						
2711	Newspapers, publishing		2	0	1	0	0	0
2751	Commercial printing except lithographic		2	0	0	0	0	0
2752	Commercial printing with lithographic		2	0	0	0	0	0
2771	Greeting card manufacturing		0	0	1	0	0	0
28	Chemical and allied products	1						
2844	Perfumes, cosmetics, other toilet preparations		1	0	0	0	0	0
32	Stone, clay, and glass products	5						
3269	Pottery products, NEC		1	0	0	0	0	0
3271	Concrete, brick, and block		0	1	0	0	0	0
3272	Concrete products, except block and brick		1	0	0	0	0	0
3273	Ready mixed concrete		1	0	0	0	1	0

TABLE 40 Profile of Canyon County Manufacturing Industries (continued)

Manufacturing Industry		Number of Firms	Employment of Firm: Employment Classification Code*					
			1	2	3	4	5	6
34	Fabricated metal product, except ordnance and transportation equipment	3						
3411	Metal cans		0	0	0	1	0	0
3442	Metals doors, sash, frames, moldings		0	0	0	1	0	0
3443	Fabricated plate work (boiler shop)		1	0	0	0	0	0
35	Machinery except electrical	3						
3522	Farm machinery and equipment		1	0	1	0	0	0
3599	Machinery and parts, NEC		1	0	0	0	0	0
37	Transportation equipment	6						
3791	Trailer coaches		0	1	0	2	1	0
3799	Transportation equipment, NEC		2	0	0	0	0	0
39	Miscellaneous manufacturing, industrial	1						
3993	Signs and ad displays		1	0	0	0	0	0
		64	36	9	7	5	6	1

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*Employment classification code: 1 = 1 to 15; 2 = 16 to 30; 3=31 to 50; 4=51 to 100; 5=101 to 500; 6 = over 500.

Identification of firms at the 4-digit SIC level is a good indicator of the size and variety of the industrial complex of Canyon County.

The major employment industries in Canyon County are SIC 20, Food and Kindred Products; SIC 24, Lumber and Wood Products, SIC 32, Stone, Clay, and Glass Products; and SIC 37, Transportation Equipment. The industries that are most diversified in terms of the variety of 4-digit SIC manufacturing products are SIC 20, Food and Kindred Products; SIC 27, Printing, Publishing, and Allied Industries; and SIC 32, Stone, Clay, and Glass Products. Thirty-two firms, one-half of the total firms in Canyon County, produce food and kindred products. These firms employ over 60% of the people employed in manufacturing industries. The food and kindred product firms include four of the seven largest manufacturing employers in the county. Recently, Amalgamated Sugar and J. R. Simplot Company have expanded their facilities and work forces, and Canyon County now has the largest sugar beet processing plant in the nation.(10)

The second largest industry in Canyon County is in transportation equipment. This industry has expanded greatly in recent years. The Nampa-Caldwell area of Canyon County, along with the Boise area of Ada County, 30 miles away, comprise a flourishing Mobile Home and Support Industry complex. Ten major manufacturers in Mobile Homes are located in this area:

Four in Canyon County and six in Ada County. These manufacturers, plus the support industries of lumber, and finished aluminum products, are capable of expanding production in the mobile home and modular home markets and are expected to participate fully in this industry's growth through 1990.

Employment in transportation equipment is expected to be one of the leading growth industries in Canyon County through the 1970's and 1980's with employment in the manufacture of mobile and modular homes reaching 1,600 by 1980 and 2,400 by 1990. Employment gains in the lumber and finished aluminum products industry will not increase as dramatically since the market in the mobile home and modular home industry is only part of their total production. Employment in Lumber and Wood Products is projected to grow from 500 in 1968 to 700 in 1980 and to 800 in 1990.

Total employment in manufacturing industries will continue to grow during the next two decades. Canyon County manufacturing employment is projected to increase from a level estimated to be 5,400 in 1970 to 6,700 in 1980 and to 7,900 in 1990.

Another group of employed is the nonagricultural self-employed. The nonagricultural self-employed include approximately 3,000 people. Employment in this group has been stable for the past decade. It is projected to remain at this level through 1990.

Manufacturing/Service Industry Relationship. Historically, Idaho's economy has centralized around the state's agriculture and timber resources. Much of the state's manufacturing industry depends on this economic base. The exports from Idaho of these natural resource-based products has provided an inflow of money which the economy has exchanged for other manufactured products and services from outside the state. The population growth patterns characteristic of an agrarian economy are present within the state and within Canyon County. Several small rural communities throughout Canyon County are primarily supported by agriculture, with little or no manufacturing base present within the community.

Many service industries do not export their services long distances. To meet the business and residential needs, these industries tend to locate to some extent within local communities and, to a larger extent, around one of the several subregional centers within the State of Idaho. The location of service-oriented industries within the state has resulted in a service-to-manufacturing industry relationship that is high when compared to the national average. In recent years, however, industry has been moving into Idaho and manufacturing employment in Idaho, particularly in Canyon County, has grown at a much faster rate than the service industries. This has caused the service-to-manufacturing industry employment ratio to decline. This contrasts directly with the trend taking place on the national scene where the ratio increased more than 15% between 1950 and 1970.

The City of Boise plays a prominent role in providing nonmanufacturing services to the State of Idaho. The Boise area relationship for service-to-manufacturing industry has been about twice that of the state during the 1960's. On the other hand, Canyon County, which is adjacent to the Boise area, has historically been below the state average. In recent years Canyon County's manufacturing base has expanded and the service-to-manufacturing industry relationship has dropped even more. This trend is expected to stabilize and eventually reverse itself as the Nampa-Caldwell area grows industrially and becomes more self sufficient in the local services provided. Even so, manufacturing industries as well as local residents will continue to look to the Boise area for certain types of services. As a result, nonmanufacturing employment in Canyon County is projected to grow from 10,840 in 1968 to 13,400 in 1980 and 17,400 by 1990.

Projected Employment and Population Growth. In forecasting Canyon County's labor force, the natural, agricultural, and industrial resource bases of the county were reviewed. Although the value of agricultural products produced in Canyon County is expected to continue to increase, the number of people directly employed in production and harvesting of agricultural products is expected to decline from an estimated level of 5,500 in 1969 to 5,300 in 1980 and 4,800 by 1990. Most of the materials considered as solid waste at the agricultural production level are either returned to the soil or disposed of by farm operations and do not significantly influence the level of solid waste generated for disposal at public sites. Solid waste materials resulting from processing of foods are treated in this report as industrial waste.

Although manufacturing employment is not the largest principal labor force component, its size is critical to the projection of other types of activities. Moreover, it is an important generator of waste. Employment in food processing firms will continue to grow, but at a reduced rate from the rapid growth during the 1960's. Employment is expected to jump from 2,940 in 1969 to 3,300 in 1980 and to 3,500 in 1990. The same pattern is expected for employment in the lumber and wood products industry. Employment in this industry jumped from 161 in 1960 to an estimated 500 by 1969. Continued growth in this industry will push employment levels to 800 by 1990.

The largest projected growth in employment and manufacturing will be in the transportation equipment industry where mobile and modular home manufacturers hold the key to local growth. Prospects for this industry appear good for the next two decades, especially if Canyon County is successful in obtaining its share of this industry's growth. Employment is expected to climb to 1,600 by 1980 and to 2,400 by 1990.

Employment in the other manufacturing industries is expected to increase at a moderate rate. Much depends on the ability of private entrepreneurs to see business opportunities in the community and to obtain the expertise and financial backing required to successfully develop a new enterprise.

Under low employment conditions, total manufacturing employment is projected to reach 6,700 by 1980 and 7,900 by 1990. On the basis of the historical relationship between employment in nonmanufacturing and manufacturing industry, nonmanufacturing employment in Canyon County is projected to reach 13,400 by 1980 and 17,400 by 1990.

Nonagriculture self-employment is expected to remain at 3,000 through 1990. The total employment in Canyon County is projected to reach 28,500 by 1980 and 33,000 by 1990.

The level of population in Canyon County in 1980 and 1990 is directly linked to the projected employment levels discussed above. Employment participation rates (percent of the total population actively employed) have increased not only throughout the nation and in Idaho, but in Canyon County as well. The employment participation rate in Canyon County increased from 37.3% in 1960 to a level estimated to be 40.6% in 1970. As more manufacturing and service industry jobs become available and more women enter the labor force on a full-time basis, employment participation rates for Canyon County are expected to continue to increase. With an increase in participation rates, population growth in Canyon County will increase at a slower rate than county employment. Even so, with rising employment as a base, Canyon County population is projected to reach 67,500 by 1980 and 76,000 by 1990 (Table 41).

Factors Influencing the Production of Solid Waste. Technology is being developed today in response to the pollution problem associated with waste materials and in response to economic pressures to utilize what are now waste products. What are noneconomic by-products of today's processing and manufacturing operations may become economically usable in tomorrow's economic complex. In general, this is more true of waste generated by larger manufacturers by virtue of the economies of scale. Of particular interest in Canyon County is the waste by-products from food processing operations. Without a change in the waste by-product-to-manufacturing product relationship, the food and kindred product industry waste materials would be expected to expand as fast as the production rise during the next 20 years. Any change (in the relationship between waste materials and production) that is derived because waste products become an economic asset is expected to influence in the form of a step-function the quantity of materials destined for waste disposal. That is, quantities of a particular material will tend to drop significantly in a short period. It is difficult to predict when such decreases in waste materials will occur. It is expected,

TABLE 41

CANYON COUNTY POPULATION, 1940 - 1990*

Estimated Population				Projected Population	
1940	1950	1960	1970	1980	1990
10,987	53,593	57,662	61,288	67,500	76,000

---

* Estimated population from Idaho Statistical Abstract, 1970 Census of Population.

however, that there will be some changes in the relationship between volume of saleable products produced and the related quantity of solid waste generated during the next 20 years. Changes in technology and economic value of waste by-products may have the impact of decreasing industrial solid waste generation per saleable product by as much as 5 to 15%.

Projection of Future Solid Waste Levels in Canyon County. Increases in solid waste materials from industrial, commercial, and residential sources relate directly to employment and population levels. On these bases projections for both future solid waste quantities and future ratios of generated waste quantity to waste quantity input (to county disposal operations) have been made for Canyon County. The forecasts do not, however, reflect an abative effect on waste quantity from improvements in packaging and recycle of special materials and commercial containers. Although passage of the Federal Resource Recovery Act of 1970 establishes recoverable wastes as a national resource, the resulting effects of significantly greater recovery of solid wastes will last affect sparsely populated areas such as Canyon County. By virtue of the unfavorable economics of residential solid waste recovery,(11) the greatest recovery effort will be seen in the areas of commercial and industrial wastes, which together in Canyon County, do not equal residential solid waste in quantity. Further, with the strong possibility of increasing constant dollar income for families, the residential solid waste generator may further increase in significance over the commercial and industrial generators, thereby negating quantity reductions from increased solid waste recovery in these areas.

Manufacturing Solid Waste. The increase in the amount of industrial waste generated by Canyon County manufacturing industry will be influenced by technological change and changes in economic value of current waste materials. These factors will have an impact on all materials, not just those that are associated with production increases. The simplifying assumption is made that the impact of change manifests only in incremental increase in generated solid waste. While manufacturing employment is projected to increase 46% between 1970 and 1990, the volume of solid waste is projected to increase 32% (Table 42).

Review of the Department of Commerce and Development's Idaho Directory of Manufacturers, 1967-68 suggests that approximately 98% of the county's employment in manufacturing is in the Nampa-Caldwell area. The fact that almost all the county's manufactured solid waste is delivered to public solid waste disposal sites is substantiated by the Battelle-Northwest survey of Canyon County manufacturers, which indicated slightly over 2% of the firms responding were using sites other than the Lake Lowell site for solid waste disposal. The increase in total county-wide solid waste generation to 1990 is affected only to a small degree by the manufacturing industries.

TABLE 42

PROJECTION OF FUTURE SOLID WASTE LEVELS IN CANYON COUNTY

Waste Type	1970	1980	1990
Manufacturing(1)(2)	1.00	1.18	1.32
Commercial(3)	1.00	1.22	1.58
Residential	1.00	1.17	1.40
Urban(4)	1.00	1.27	1.61
Rural	1.00	1.06	1.19

---

(1) Includes agricultural processing solid waste materials.

(2) 98% of the County's manufacturing employment is within the urban (Nampa-Caldwell) area.

(3) 88% of County retail sales occurs within the urban (Nampa-Caldwell) area.

(4) Includes Nampa, Caldwell and local area.

Increases in manufacturer's volume of solid waste is expected to make up only 14% of the total county-wide increase in solid waste volume to 1990 (Table 43).

Commercial Solid Waste. Commercial solid waste is expected to increase at the same rate as industry employment, or 58% between 1970 and 1990. As would be expected, a large share of the total commercial solid waste generated in Canyon County comes from the Nampa-Caldwell area. Review of Sales Management indicates that approximately 88% of the total retail sales in the county were made in the Nampa-Caldwell area. On this basis, Lake Lowell (and its replacement) is expected to continue to absorb 88% of the county's commercial solid waste. Increases in commercial solid waste for the period to 1990 are expected to account for 27% of the county-wide solid waste increase.

Residential Solid Waste. Between 1970 and 1990 residential population is projected to increase 24%, and residential solid waste is projected to increase 40%. Residential solid waste is by far the most significant of the solid waste generators, accounting for 59% of the solid waste increase. The relationship between the amount of all types of waste generated and the amount of all types of waste entering the county's disposal operations is expected to remain essentially constant over the next 20 years. (The effect of increased utilization of wastes is considered in this projection.) The percentage of residential waste that enters the disposal operations,

TABLE 43

SOLID WASTE INCREASE IN 1970-1990 PERIOD BY WASTE TYPE

Type of Waste	Contribution (%)
Manufacturing	14
Commercial	27
Residential	59

however, is expected to increase, particularly that generated in the rural areas of the county. Increasingly strict regulation of burning and on-site burial of wastes will cause a greater percentage of the waste to be disposed of in the county operations. The percentage of residential generated wastes that enter the county disposal operations is expected to increase from the estimated current level of 67% to 90% by 1990.

Current Waste Input Estimate. Current waste input estimates for Canyon County are based on a survey of waste inputs to the Canyon County landfill near Nampa. For a period of 37 working days the net waste weight for each truckload entering the landfill was recorded. All collection service vehicles and all commercial and industrial haulers were included in the survey, but private automobiles, pickup trucks and small trailers were excluded. Each load of waste was classified as residential, commercial or industrial by the drivers' report of the type of route, or by visual inspection of the contents. All wastes which could not be classified either as residential or commercial were considered industrial.

The per capita daily waste input shows a seasonal variation. In the spring, for example, a large volume of tree prunings and other residential yard waste is collected. Since the purpose of this study was not to evalute this type of seasonal variation in exhaustive detail, the observations of waste input were made during the months of November, December, and April and are assumed to be representative of the yearly average.

(The average daily input of each type of waste is shown in Table 44.) At the time this data was taken, the collection services in Nampa and Caldwell were servicing a total population of approximately 28,360. Assuming that the collection service handles 100% of that portion of its customers' waste which finds its way to the landfill, the data gives a per capita daily waste input of 3.0 lb.

A recent study(12) found a strong correlation between the population density of rural areas and per capita waste production. It predicts that an area with a population density of 120 people per square mile, such as Canyon County, would have a per capita waste production of approximately 2.8 lb/day, in good agreement with the observed 3.0 lb. The Canyon County landfill serves an additional 21,423 people who do not subscribe to a collection service. Most of these people do not live in the cities and many do not dispose of all their solid wastes in the landfill. Many burn the combustible portion of their refuse and either bury the ashes and noncombustibles or haul them to the landfill. Some people bury most of their waste on their own property. Because of the alternatives to the landfill available to these people, it is estimated that their average per capita daily input to the landfill is only two-thirds of the average for people served by the collection service, or 2.0 lb. Their estimated combined input to the Canyon County landfill is 42,846 lb/day. This brings the

TABLE 44

AVERAGE OBSERVED DAILY WASTE INPUT TO CANYON COUNTY LANDFILL NEAR NAMPA

Waste Classification	Average Daily Input (lb)	Percentage of Total Daily Input (%)
Residential	83,785	62.5
Commercial	26,425	19.7
Industrial(1)	23,843	17.8
Total	134,053	100.0

---

(1) Includes food processing and agricultural wastes.

total estimated daily input to 176,899 lb. The average density of the waste hauled to the Canyon County landfill was approximately 300 lb/yd^3. This gives an average daily input volume of 490 yd^3.

Current waste input estimates for the other disposal sites in Canyon County are based on the data collected at Lake Lowell. As noted previously, the Nampa-Caldwell area served by the Canyon County landfill accounts for approximately 88% of the commercial solid waste generation in the county. The remaining 12% was allocated to the population outside of the Nampa-Caldwell area, and the resulting commercial solid waste generation per capita was distributed among the various disposal sites according to the population served by each. The population served by each site was taken from the Recommended Solid Waste Disposal Plan for Canyon County, published by the Idaho Department of Health, June 26, 1969. The estimate of the total county population in that report varies less than 0.5% from the 1970 Census of Population.

Per capita residential waste inputs were obtained by dividing the observed residential waste input by the population served by collection services at the time the observations were made. The per capita input from residents not served by a collection service is estimated at 0.67 times that of a resident served. The 1970 estimated input to the Canyon County Landfill was corrected to reflect the increase in population served which resulted when, after the waste input observations were made, Nampa adopted a uniform collection policy.

The current solid waste inputs to the disposal sites in Canyon County are given in Table 45. The waste density observed at the Lake Lowell site was 300 lb/yd^3, with much of the waste arriving in compacting collection trucks. The average density at the other sites (where no compacting trucks are used) is estimated at 150 lb/yd^3.

Waste Input Projections, 1970 to 1990. The projections of solid waste generation increases (Table 42) were applied to the current estimated input levels to project the solid waste inputs to each site through 1990. The residential, commercial and industrial waste input changes were projected separately for each site to obtain the totals shown in Table 46. The volume estimates in this table were based on the assumption that the trucked density of the waste to each site would remain constant. If compactor trucks are used at some of the sites, this would affect the average trucked density of the solid waste arriving at the site.

The present Canyon County landfill at Lake Lowell will be full in less than two years. The projections assume that another site can be obtained in the Nampa-Caldwell area when the present site is full. The situation at the other sites is not as critical since they have either longer expected useful lifetimes or suitable sites are more readily available, or both.

TABLE 45

ESTIMATED WEEKLY WASTE INPUTS TO CANYON COUNTY SOLID WASTE DISPOSAL SITES

Site	Population Served(1)	Weekly Waste Input (lb)	Weekly Waste Input (yd^3)
Canyon County Landfill (Lake Lowell)	49,573	1,086,000	3620(2)
Black Canyon (Middleton)	3,285	45,600	304(3)
Parma	4,276	59,400	396(3)
Central Cove	4,187	58,000	387(3)
Melba	885	12,300	82(3)

---

(1) From recommended Solid Waste Disposal Plan for Canyon County, Idaho State Department of Health, June 26, 1969.

(2) Average density of 300 lb/yd^3.

(3) Average density of 150 lb/yd^3.

TABLE 46

PROJECTED WEEKLY WASTE INPUTS TO CANYON COUNTY LANDFILLS

1970-1990

Site	1970 (lb/wk) (yd^3/wk)	1980 (lb/wk) (yd^3/wk)	1990 (lb/wk) (yd^3/wk)
Canyon County Landfill (Lake Lowell)	1,086,000 (3,619)	1,353,000 (4,511)	1,800,000 (5,670)
Black Canyon (Middleton)	45,600 (304)	56,700 (378)	73,100 (487)
Parma	59,400 (396)	73,800 (482)	95,100 (634)
Central Cove	58,000 (387)	72,300	93,000 (621)
Melba	12,300 (82)	15,200 (102)	19,685 (131)

The total solid waste input to the county disposal sites is projected to increase by approximately 24% by 1980, while the 1990 level is projected to be 60% above the 1970 level.

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APPENDIX A

REVIEW OF STATE ROAD AND HIGHWAY REGULATIONS

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REVIEW OF STATE ROAD AND HIGHWAY REGULATIONS

A review of state road and highway regulations was undertaken to assure that the Multi-Mover would comply with these regulations when operating in the highway mode. The review includes identification of road envelope parameters, weight limits, speed limits and operating equipment requirements. Each state was requested to send a copy of its regulations governing the use of vehicles similar to the Multi-Mover. The analysis of road and highway regulations will also result in design modification leading to a better vehicle for highway operations.

The Multi-Mover is 8-1/2 ft wide by 8-1/2 ft high by 22 ft long. It is 6 in. wider than regulations in most states allow and must have an oversize permit to operate on the highways. The vehicle meets the minimum weight requirements of 18,000 lb on each axle. Clearance lights, while not required, are desirable. The Multi-Mover would also require an all-weather cab with windshield wipers and safety glass. Many states require a horn on this type of vehicle.

Highway Envelope. The legal highway envelope in which a vehicle can operate without an oversize permit is defined as follows:

Width	8 feet
Height	12 feet 6 inches
Length	35 feet

These parameters are based on data derived from review of highway regulations (Table A-1). The width of 8 ft is common to all states except Hawaii (9 ft) and Rhode Island (8-1/2 ft). The height of 13-1/2 ft is common to all states except Colorado, which has a 12-1/2 ft limit and is the most restrictive state. Length restrictions vary from 35 to 55 ft. Some states will issue an oversize permit only on a per-trip basis, while others will issue them on a periodic basis. Additionally, some states will waiver this requirement for governmental vehicles.

Weight Limits. In most states, the allowable weight is based on the axle loadings, but some states use gross vehicle weight. Axle loading was chosen over gross vehicle weight because of the preference of the states themselves. Most states limit a single axle to 18,000 lb while others restrict axle loading on specific axles. For example, Tennessee limits the weight on the steering axle to 12,000 lb. A combination of axle loading and pounds per square inch of tire surface is the criterion in a few states. The state of Hawaii is the most restrictive with 60 lb/in.^{2} tire loading. However, the requirements of the next most restrictive state, Louisianna, with 450 lb/in.^{2} is more representative of the other states. Therefore, the weight limitation for a Multi-Mover should be 450 lb/in.^{2} of tire surface and 18,000 lb per single axle.

Speed Limits. Regulations on speed did not identify vehicles similar to the Multi-Mover; most states limit speed on all vehicles on the basis of "whatever is safe and proper." However, Pennsylvania has a maximum speed limit of 45 miles per hour for earthmoving equipment. Only Oregon has a limiting speed, where a minimum of 20 miles per hour on all grades on two-lane highways is required. The Multi-Mover should have a gear ratio sufficient to provide at least 20 miles per hour on all grades and 35 miles an hour on level highway.

OPERATING EQUIPMENT REQUIREMENTS

Lights. The lighting requirements for earthmoving equipment such as the Multi-Mover are vague. However, all states require headlights, taillights, and stoplights on all vehicles operating on the highway. Earthmoving equipment operating off the road in some states are required to have a single light which is visible from 500 ft. Vehicles operating on the highway must have headlights visible for a distance of 500 ft and mounted 24 in. off the ground and at least 54 in. apart. Taillights must be 20 in. off the ground and no more than 72 in. apart, and visible for a distance of 500 ft. Clearance lights are required for large vehicles and trailer rigs. The Multi-Mover, therefore, must have two headlights, two taillights, two stoplights, and clearance lights as required.

Brake Requirements. Most states require that all vehicles operating on the highways have a service brake system, a parking brake, and brakes on all wheels. All vehicles manufactured after 1968 must have a two-part service brake system in which each part controls the brakes on at least two wheels independently from the other part. The service brake system must be capable of stopping the Multi-Mover in 40 ft at 20 miles per hour and capable of applying a braking force of 43.5% of the vehicle's gross weight.

Cab Requirements. Several states require that road maintenance equipment traveling on the highways have an all-weather cab. However, the majority of states have no cab requirements. If an all-weather cab is included as part of the Multi-Mover, it must have safety glass, windshield wipers, and a horn.

APPENDIX B

FIELD EVALUATION DATA SHEETS

APPENDIX B

FIELD EVALUATION DATA SHEETS

MULTIMOVER EVALUATION--Y-49552

DATA SHEET--HIGHWAY MODE

Date June 25, 1970 Data By R. C. Kelley

Weather Conditions Clear, Warm

Move from Site Lake Lowell To Site Black Canyon

Road Distance Between Sites 15 miles one way

	Multimover	Crawler Tractor	Remarks
1. Trip preparation time (loading, disengage front wheel drive, etc.)	None	Load 15 min.	Crawler Tractor Total Round Trip 2 hr, 10 min.
2. Travel time of equipment	2 hr, 30 min round trip	40	
3. Preparation time for job (unloading, engage front wheel drive, etc.)	None	Unload 10 min.	
4. Fuel Consumption	10.0 gal.	None	
5. Fuel Cost	$1.79	None	Lowboy rental for crawler tractor - $52.00
6. Travel time of operator(s)	2 hr, 30 min.	2 hr. 10 min.	
7. Down time for maintenance	None	None	
8. Cost of repairs, parts and labor	None	None	
9. Cost of over legal permits	None	None	

MULTIMOVER EVALUATION--Y-49552

DATA SHEET--HIGHWAY MODE

Date June 30, 1970

Data By W. E. Masters

Weather Conditions Clear, Warm

Move from Site Lake Lowell

To Site Central Cove

Road Distance Between Sites 12 miles one way

	Multimover	Crawler Tractor	Remarks
1. Trip preparation time (loading, disengage front wheel drive, etc.)	None	Load 13 min.	Crawler Tractor Total Round Trip 2 hr, 12 min.
2. Travel time of equipment	2 hr, 9 min. Round Trip	46 min. One Way	
3. Preparation time for job (unloading, engage front wheel drive, etc.)	None	Unload 10 min.	
4. Fuel Consumption	11.2 gal.	None	Includes some working time for Multimover fuel
5. Fuel Cost	$2.00	None	Lowboy rental for crawler tractor - $52.00
6. Travel time of operator(s)	2 hr, 9 min.	2 hr, 12 min	
7. Down time for maintenance	None	None	
8. Cost of repairs, parts and labor	None	None	
9. Cost of over legal permits	None	None	

MULTIMOVER EVALUATION--Y-49552

DATA--COMPACTION (WEIGHT BASIS)

Data By W. E. Masters

Site Lake Lowell Date 11-3-69 thru' 11-10-69

Weather Conditions Cloudy Rainy

Type of Cover Material Sandy loam

Total Cell Depth, Ft. 3 1/2 (approximately)

	Multimover	Crawler Tractor	Remarks
1. Cell No.		L-2	
2. Waste Lift depth, inches		12	
3. Waste lift length & width, ft.		60 x 155	
4. Amount of water added (a) per lift (b) total	(a) (b)	(a) (b) .10 inches	Rain
5. Time to spread wastes per lift		60 min.	
6. Time to apply water per lift		None	
7. Number of waste compaction passes/lift		1	
8. Time per compaction pass, one direction		55 sec. forward 45 sec. reverse	
9. Total initial weight of waste lbs.*		535,990	Includes 82,600 lbs. of waste seed
10. Compacted volume of waste, C.Y.		528.0	
11. In-Place waste density; lbs/C.Y.		1015	
12. Intermediate cover added (if any) inches, loose thickness		None	
13. Intermediate cover added (if any) cubic yards total		None	
14. Total number of waste lifts		6	
15. Cover lift depth, inches, loose		6	
16. No. of compaction passes/cover lift		1	
17. Time per compaction pass, total cell		12 min.	
18. Cover material added, C.Y., loose		172	
19. Cover lift depth, inches, compacted		6	
20. In-Place cover lift density, lbs/C.Y.		2650	approximate
21. Total compacted vol. of waste plus cover, C.Y. *		700	
22. Total in-place density: $\frac{\text{Weight of waste \& soil cover}}{\text{Total in-place vol.}}$ lbs/C.Y.		1417	

*From separate Tally Sheet; enter totals here.

MULTIMOVER EVALUATION--Y-49552

DATA--COMPACTION (WEIGHT BASIS)

Data By C. H. Henager

Site Lake Lowell Date 10-29 thru' 10-31-69

Weather Conditions Clear, cool

Type of Cover Material Sandy loam

Total Cell Depth, Ft. 3 1/2 (approximately)

	Multimover	Crawler Tractor	Remarks
1. Cell No.	L-1		Multimover cell
2. Waste Lift depth, inches	12		with assistance
3. Waste lift length & width, ft.	50 x 110		of crawler tractor
4. Amount of water added (a) per lift (b) total	(a) (b) None	(a) (b)	in spreading top 3 lifts
5. Time to spread waste per lift	60 min.		
6. Time to apply water per lift	- -		
7. Number of waste compaction passes/lift	1		
8. Time per compaction pass, one direction	30 seconds		
9. Total initial weight of waste lbs.*	260,180		includes 23,300 lbs of waste seed
10. Compacted volume of waste, C.Y.	287.2		
11. In-Place waste density: lbs/C.Y.	908		
12. Intermediate cover added (if any) inches, loose thickness	None		
13. Intermediate cover added (if any) cubic yards total	None		
14. Total number of waste lifts	7		
15. Cover lift depth, inches, loose	8		
16. No. of compaction passes/cover lift	1		
17. Time per compaction pass, total cell	16 min.		
18. Cover material added, C.Y., loose	96.1		
19. Cover lift depth, inches, compacted	6		
20. In-Place cover lift density, lbs/C.Y.	3000		approximate
21. Total compacted vol. of waste plus cover, C.Y.	383.3		
22. Total in-place density: Weight of waste & soil cover / Total in-place vol. lbs/C.Y.	1430		

* From separate Tally Sheet; enter totals here.

MULTIMOVER EVALUATION--Y-49552

DATA--COMPACTION (WEIGHT BASIS)

Data By W. E. Masters

Site Lake Lowell Date 11-11-69 thru' 11-13-69

Weather Conditions Clear, Warm

Type of Cover Material Sandy gravel

Total Cell Depth, Ft. 2 1/2 (approximately)

Note 1. Lift 1 received only 2 compaction passes with multimover down for repairs. Lift 2 spread by crawler tractor, compacted by Multimover.

	Multimover	Crawler Tractor	Remarks
1. Cell No.	L-3		
2. Waste Lift depth, inches	24, 96, 12		
3. Waste lift length & width, ft.	50 x 78		
4. Amount of water added (a) per lift (b) total	(a) (b) None	(a) (b)	
5. Time to spread wastes per lift	30 min		
6. Time to apply water per lift	None		
7. Number of waste compaction passes/lift	Lift (1) 2 Lift (2,3) 4		See Note 1
8. Time per compaction pass, total cell	25 min		
9. Total initial weight of waste lbs.*	137,960		
10. Compacted volume of waste, C.Y.	117.1		
11. In-Place waste density: lbs/C.Y.	1178		
12. Intermediate cover added (if any) inches, loose thickness	None		
13. Intermediate cover added (if any) cubic yards total	None		
14. Total number of waste lifts	3		
15. Cover lift depth, inches, loose	8		
16. No. of compaction passes/cover lift	4		
17. Time per compaction pass, total cell	20 min		
18. Cover material added, C.Y., loose	86.6		
19. Cover lift depth, inches, compacted	6		
20. In-Place cover lift density, lbs/C.Y.	3000		approximate
21. Total compacted vol. of waste plus cover, C.Y.	182.1		
22. Total in-place density: $\frac{\text{Weight of waste \& soil cover}}{\text{Total in-place vol.}}$ lbs/C.Y.	2021		

*From separate Tally Sheet; enter totals here.

MULTIMOVER EVALUATION--Y-49552

DATA--COMPACTION (WEIGHT BASIS)

Data By W. E. Masters

Site Lake Lowell Date 4-27-70 thru' 5-1-70

Weather Conditions Cool, Windy

Type of Cover Material Sandy loam

Total Cell Depth, Ft. 4 (approximately)

	Multimover	Crawler Tractor	Remarks
1. Cell No.		L-6	
2. Waste Lift depth, inches		32	
3. Waste lift length & width, ft.		45 x 90	
4. Amount of water added (a) per lift (b) total	(a) (b)	(a) (b) None	
5. Time to spread wastes per lift		1 hr., 15 min.	
6. Time to apply water per lift		None	
7. Number of waste compaction passes/lift		3	
8. Time per compaction pass, total cell		20 min.	
9. Total initial weight of waste lbs.*		214, 960	
10. Compacted volume of waste, C.Y.		356.6	
11. In-Place waste density: lbs/C.Y.		603	
12. Intermediate cover added (if any) inches, loose thickness		None	
13. Intermediate cover added (if any) cubic yards total		None	
14. Total number of waste lifts		3	
15. Cover lift depth, inches, loose		6	
16. No. of compaction passes/cover lift		3	
17. Time per compaction pass, total cell		15 min.	
18. Cover material added, C.Y., loose		66.6	
19. Cover lift depth, inches, compacted		6	
20. In-Place cover lift density, lbs/C.Y.		2650	approximate
21. Total compacted vol. of waste plus cover, C.Y.		423.2	
22. Total in-place density: $\frac{\text{Weight of waste \& soil cover}}{\text{Total in-place vol.}}$ lbs/C.Y.		961	

*From separate Tally Sheet; enter totals here.

MULTIMOVER EVALUATION--Y-49552

DATA--COMPACTION (VOLUME BASIS)

Data By W. E. Masters

Site Lake Lowell Date 6-4-70

Weather Conditions Clear, Hot

Type of Cover Material None

Total cell depth, ft. 1 (approximately)

	Multimover	Crawler Tractor	Remarks
1. Cell No.	L-8		
2. Waste lift depth, inches	24		
3. Waste lift length & width, ft.	18 x 34		
4. Amount of water added (a) per lift (b) total	(a) 343 & 686gal (b) 1029 gal	(a) (b)	
5. Time to spread wastes per lift	- -		
6. Time to apply water per lift	Lift 1 10 min Lift 2 20 min		
7. Number of waste compaction passes/lift	2		
8. Time per compaction pass	- -		
9. Total initial volume of waste, C.Y.	96		Truck compacted
10. Compacted volume of waste, C.Y.	21.8		
11. Waste compaction ratio: $\frac{\text{Trucked Vol.}}{\text{In-Place Vol.}}$	4.4:1		
12. Intermediate cover added, (if any) inches, loose thickness	None		
13. Intermediate cover added, (if any) cubic yards total	None		
14. Total number of waste lifts	2		
15. Cover lift depth, inches, loose	None**		
16. No. of compaction passes/cover lift	- -		
17. Time per compaction pass	- -		
18. Cover material added, C.Y.	- -		
19. Cover lift depth, inches, compacted	- -		
20. In-place cover lift density, lbs/C.Y.	- -		
21. Total compacted vol. of waste plus cover, C.Y.	- -		
22. Total compaction ratio: $\frac{\text{Trucked Waste Vol.} + \text{Cover Vol.}}{\text{Total In-Place Volume}}$	- -		

** Cover material compaction was not a part of this test. Cell was covered later as part of the landfill.

*From separate Tally Sheet; enter totals here.

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